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A Study on Meiosis and Its Applications

Sudesh Kumari

Abstract – Meiosis is a type of cell division that, in humans, occurs only in male testes and female ovary tissue, and, together with fertilization, it is the process that is characteristic of sexual reproduction. Meiosis serves two important purposes: it keeps the number of chromosomes from doubling each generation, and it provides genetic diversity in offspring. In this it differs from mitosis, which is the process of cell division that occurs in all somatic cells.

INTRODUCTION

All of our somatic cells except the egg and sperm cells contain twenty-three pairs of chromosomes, for a total of forty-six individual chromosomes. This number, twenty-three, is known as the diploid number. If our egg and sperm cells were just like our somatic cells and contained twenty-three pairs of chromosomes, their fusion during fertilization would create a cell with forty-six chromosome pairs, or ninety-two chromosomes total. To prevent that from happening and to ensure a stable number of chromosomes throughout the generations, a special type of cell division is needed to halve the number of chromosomes in egg and sperm cells. This special process is meiosis.

Meiosis creates haploid cells, in which there are twenty-three individual chromosomes, without any pairing. When gametes fuse at conception to produce a zygote, which will turn into a fetus and eventually into an adult human being, the chromosomes containing the mother's and father's genetic material combine to form a single diploid cell. The specialized diploid cells that will eventually undergo meiosis to produce the gametes are called primary **oocytes** in the female ovary and primary spermatocytes in the male testis. They are set aside from somatic cells early in the course of fetal development.

Even though meiosis is a continuous process in reality, it is convenient to describe it as occurring in two separate rounds of nuclear division. In the first round (meiosis I), the two versions of each chromosome, called homologues or homologous chromosomes, pair up along their entire lengths and thus enable genetic material to be exchanged between them. This exchange process is called crossing over and contributes greatly to the amount of genetic variation that we see between parents and their children. Subsequently, the two homologues are pulled toward opposite ends of their surrounding cell, thus creating a

haploid cluster of chromosomes at each pole, at which point division occurs, separating the two clusters. Meiosis I is therefore the actual reduction division. At the end of meiosis I, each chromosome is still composed of two sister strands (chromatids) held together by a particular DNA sequence of about 220 nucleotides, called the centromere. The centromere has a disk-shaped protein molecule (kinetochore) attached to it that is important for the separation of the sister chromatids in the second round of meiosis (meiosis II). Meiosis II is essentially the same division process as mitosis. Through the separation of the two sister chromatids, a total of four daughter cells, each with a haploid set of chromosomes, are created.

RESEARCH STUDY

Meiosis must be preceded by the S phase of the cell cycle. This is when DNA replication (the copying of the genetic material) occurs. Thus, each chromosome enters meiosis consisting of two sister chromatids joined at the centromere. The first stage of meiosis is a stage called prophase I. First, the DNA of individual chromosomes coils more and more tightly, a process called DNA condensation. The sister chromatids then attach to specific sites on the nuclear envelope that are designed to bring the members of each homologous pair of chromosomes close together. The sister chromatids line up in a fashion that is precise enough to pair up each gene on the DNA molecule with its corresponding "sister gene" on the homologous chromosome. This four-stranded structure of maternal and paternal homologues is also called a bivalent.

Prophase I is the process of crossing over, in which fragments of DNA are exchanged between the homologous sister chromatids that form the paired DNA strands. Crossing over involves the physical breakage of the DNA double helix in one paternal and one maternal chromatid and joining of the respective ends. Under the light microscope, the points of this

exchange can often be seen as an X-shaped structure called a chiasma.

The exchange of genetic material means that new combinations of genes are created on two of the four chromatids: Stretches of DNA with maternal gene copies are mixed with stretches of DNA with paternal copies. This creation of new gene combinations is called "recombination" and is very important for evolution, since it increases the amount of genetic material that evolution can act upon. A statistical technique known as linkage analysis uses the frequency of recombination to infer the location of genes, such as those that increase a person's risk for certain diseases.

At the beginning of metaphase I, the nuclear envelope has dissolved, and specialized protein fibers called microtubules have formed a spindle apparatus, as also occurs in the metaphase of mitosis. These microtubules then attach to the kinetochore protein disks on the two centromeres of the homologous pair of chromosomes. However, there is an important difference between mitosis and meiosis in the way this attachment occurs. In mitosis, microtubules attach to both faces of the kinetochore and thus separate sister chromatids when they pull apart. In meiosis, because the chiasma structures still hold the homologous sister chromatids together, only one face of each kinetochore is accessible to the microtubules. Since the microtubules can only attach to one face of the kinetochore, the sister chromatids will be drawn to opposite poles as a pair, without separation of the individual chromatids.

At the end of metaphase I, the pairs of homologues line up on the metaphase plate in the center of the cell, the spindle apparatus is fully developed, and the microtubules of the spindle fibers are attached to one side of each of the two kinetochores. In anaphase I, the microtubules begin to shorten, thus breaking apart the chiasmata and pulling the centromeres with their respective sister chromatids toward the two cell poles. The centromeres do not divide, as they do in mitosis. At the final stage of meiosis I, called telophase I, each cell pole has a cluster of chromosomes that corresponds to a complete haploid set, one member of each homologous chromosome pair.

THE SOURCES OF GENETIC DIVERSITY

It is completely random whether the maternal or paternal chromosome of each pair ends up at a particular pole. The orientation of each pair of homologous chromosomes on the metaphase plate is random, and a mixture of maternal and paternal chromosomes will be drawn toward the same cell pole by chance. This phenomenon is often called "independent assortment," and it creates new combinations of genes that are located on different chromosomes. Thus, we have two levels of gene reshuffling occurring in meiosis I. The first occurs during recombination in prophase I, which creates new

combinations of genes on the same chromosome. In contrast to mitosis, the sister chromatids of a chromosome are not genetically identical because of the crossing-over process. Anaphase I then adds the independent assortment of chromosomes to create new combinations of genes on different chromosomes. A total of 2^{23} (8.4 million) possible combinations of parental chromosomes can be produced by one person, and recombination further increases this to an almost unlimited number of genetically different gametes.

MEIOSIS II

Once both cell poles have a haploid set of chromosomes clustered around them, these chromosomes divide mitotically (without reshuffling or reducing the number of chromosomes during division) during the second part of meiosis. This time, the spindle fibers bind to both faces of the kinetochore, the centromeres divide, and the sister chromatids move to opposite cell poles. At the end of meiosis II, therefore, the cell has produced four haploid groups of chromosomes. Nuclear envelopes form around each of these four sets of chromosomes, and the cytoplasm is physically divided among the four daughter cells in a process known as cyto-kinesis.

In males, the four resulting haploid sperm cells all go on to function as gametes (spermatozoa). They are produced continuously from puberty onwards. In females, all primary oocytes enter meiosis I during fetal development but then arrest at the prophase I stage until puberty. During infancy and early childhood, the primary oocytes acquire various functional characteristics of the mature egg cell. After puberty, one oocyte a month completes meiosis, but only one mature egg is produced, rather than the four mature sperm cells in males. The other daughter cells, called polar bodies, contain little cytoplasm and do not function as gametes.

CONCLUSION

Meiosis is a very intricate process that requires, among other things, the precise alignment of homologous chromosome pairs and correct attachment of microtubules. During meiosis, errors in chromosome distribution may occur and lead to chromosomal aberrations in the offspring. One example is Down syndrome, where affected children carry three copies of chromosome 21 (trisomy 21). This may be explained by the failure of paired chromosomes or sister chromatids to separate in either sperm or egg, leading to the presence of two copies of chromosome 21. After fertilization with a normal gamete, the zygote will carry three copies, which leads to several phenotypic abnormalities, including mental retardation.

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