Cytokinesis = 1412 words

Field of study: Classical transmission genetics, developmental genetics

Significance: Cytokinesis is one of the most significant events that occur during the last phase of cell divisions. Some distinct features exist in cytokinesis of microbes, animal and plant cells. The partitioning of cytoplasm during meiosis and related sexual reproduction also act to determine the fate of resulted daughter cells.

Key terms

binary fission: the type of cell division in prokaryote by which the plasma membrane and cell wall grow inward and divide the cell in two

cytokinesis: follows mitosis; a process that divides the entire cell into two new cells

interphase: precedes mitosis in cell cycle; a period of intense cellular activities that include the DNA replication

mitosis: nuclear division, a process of allotting a complete set of chromosomes to two daughter nuclei

meiosis: a type of cell division that leads to production of gametes (e.g. sperm and egg) during sexual reproduction

the cell cycle: a regular and repeated sequence of events pass through by dividing cells

Events Leading to Cytokinesis

Cytokinesis is the division or partitioning of the cytoplasm following the equal division of genetic material into the daughter cells. Before a given cell can divide, its genetic material – deoxyribonucleic acid or DNA has to be duplicated through DNA replication. The identical copies of DNA are then separated into one of the two daughter cells through a multiple step process, of which details vary among prokaryotes, plants and animals. With a single chromosome and no nucleus, prokaryotes (such as bacteria) utilize a simple method of cell division called binary fission (meaning “splitting in two”). The single circular DNA molecule is replicated rapidly and split into two. Each of the two circular DNA then migrates to the opposite pole of bacterial cell. Eventually, one bacterial cell splits into two through binary fission. On average, a bacterial cell can go through the whole process of cell division within 20 minutes.

In eukaryotes, cell division is a more complex process than in prokaryote due to the presence of nucleus and multiple DNA molecules (chromosomes). Each of the DNA will need to be replicated exactly once in preparation for the division. The replication process is completed during the interphase. Once replicated, two copies of the same DNA are connected together in a region called centromere. The DNA molecules then go through a process of shortening, condensing and packing with proteins to form chromosomes visible through light microscope. Chromosomes then migrate and line up at the equator plate of the parent cell before they split. The divided chromosomes are then pulled to two opposite poles and the two daughter cells separate in the middle (equator) of the parent cell. These multiple steps include interphase (cell growth and DNA replication), prophase (disintegration of nuclear envelope, formation of spindle fibers, condensation of chromosomes), metaphase (lining up of chromosomes at equator plate), anaphase (split of two sister chromatids) and telophase (completion of migration of chromatids to opposite poles). Although animal and plant cells share many common features in DNA replication and mitosis, some noticeable differences in interphase and cytokinesis exist. Even within the animal kingdom, cytokinesis may vary with the type of cell division. During oogenesis (the process of forming egg), in particular, both meiosis I and meiosis II engages in unequal partitioning of cytoplasm that is distinct from normal mitosis of animal and plant cells.

Cytokinesis in Prokaryotes and Animals

In bacteria, the circular chromosome attaches to the plasma membrane at one point. The chromosome is then replicated. The two copies are attached to the membrane at nearby points. As the cell elongates, new plasma membrane is added between the attachment points, pushing them apart. As the two chromosomes move toward opposite poles of the cell, the plasma membrane grows inward at the middle (equator) of the cell. The parent cell splits into two daughter cells, completing binary fission. Each daughter cell receives exactly one copy of DNA and about half of the cytoplasm.

In animal cells, cytokinesis normally begins during telophase following the completion of chromosome segregation. First, microfilaments attached to the plasma membrane form a ring around the equator of the cell. This ring then contracts and constricts the cell’s equator, much like pulling the drawstring around the waist of a pair of sweatpants. Eventually the “waist” is pinched through and contracts down to nothing, partitioning the cytoplasm equally into two daughter cells.

Cytokinesis in Plants

Two events that occur in cell division are unique to plants. First, the nucleus must migrate to the center of the cell before mitosis can begin. The nucleus becomes anchored initially by cytoplasmic strands, which gradually merge to form a transverse sheet of cytoplasm that bisects the cell in the plane where it ultimately will divide. This sheet of phragmosome, contains both microtubules and actin filaments involved with its formation. Secondly, cytokinesis in plant cell mitosis is quite different from that of animal cell. The presence of a tough cell wall (made up of cellulose, lignin, hemicellulose, etc) makes it nearly impossible to splitting one cell into two by pinching the “waist”. Instead, cell division occurs by formation of a cell plate. In early telophase, an initially barrel-shaped system of microtubules called phragmoplast form between the two daughter nuclei. The cell plate is then initiated as a disk suspended in the phragmoplast.

The cell plate is formed by fusion of secretory vesicles derived from the Golgi apparatus. Apparently, the carbohydrate-filled vesicles are directed to the division plane by the phragmoplast microtubules, possibly with the help of motor proteins. The vesicles contain matrix molecules, hemicelluloses and/or pectins that form the cell plate. As the vesicles fuse, their membranes contribute to the formation of the plasma membrane on either side of the cell plate. When enough vesicles have fused, the edges of the cell plate merge with the original plasma membrane around the circumference of the cell, completing the separation of two daughter cells. In between the two plasma membranes lie the middle lamella that separates two daughter cells. Each of the two daughter cells then deposits a primary wall next to the middle lamella. In addition, each daughter cell deposits a new layer of primary wall around the entire protoplast. This new wall is continuous with the wall at the cell plate. The original wall of the parent cell stretches and ruptures as the daughter cells grow and expand.

Cytokinesis in Sexual Reproduction

In animal oogenesis, the formation of ova or eggs occurs in the female reproductive organs called ovaries. Although the daughter cells resulting from the two meiotic divisions receive equal amounts of genetic material, but they do not receive equal amounts of cytoplasm. Instead, during each division, almost all the cytoplasm is concentrated in one of the two daughter cells. In meiosis I, unequal partitioning of cytoplasm during cytokinesis produces the first polar body almost void of cytoplasm, and the secondary oocyte with almost all cytoplasm from the mother cell – primary oocyte. During meiosis II, cytokinesis again partitions almost all cytoplasm to one of the two daughter cells – ootid, which will eventually grow and differentiate into mature ovum or egg. Another daughter cell, the secondary polar body, receives almost no cytoplasm. This concentration of cytoplasm is necessary for the success of sexual reproduction by animals because a major function of the mature ovum is to nourish the developing embryo following fertilization.

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See also:

Further Reading

Grant, M. C. The trembling giant. *Discover*, October 1993. Excellent illustrations on asexual reproduction through mitosis of plant cells/tissues. Aspen groves are really single individuals: huge, slowly spreading from the roots of the original parent tree.

Murray, A.W. and M.W. Kirschner. What controls the cell cycle. *Scientific American*, March 1991. Illuminating description of a group of proteins that are involved in cell cycle control. The synthesis, processing, and degradation of these proteins seems to regulate the progression of a cell through various stages of the cell cycle.

Murray, A.W. and M.W. Kirschner. 1993. *The Cell Cycle: An Introduction*. New York: Oxford Univ. Press. Very informative without too many scientific jargons.

Shaul, Orit, Marc van Montagu and Dirk Inze. 1996. Regulation of cell divisions in *Arabidopsis*. *Critical Reviews in Plant Sciences* 15: 97-112. An contemporary review on what we know about plant cell cycle regulation and cell divisions. For more serious readers.

Staiger, Chris and John Doonan. 1993. Cell divisions in plants. Current Opinion in Cell Biology 5: 226-231. A condensed version on plant cell divisions. Provide a quick overview.