MODULE 2: REPRODUCTIVE CELL DIVISION, DIFFERENTIATION AND GROWTH OF CELLS Error! Bookmark not defined.

UNIT 1: CELL DIVISION PROCESSES IN PROKARYOTIC AND EUKARYOTIC CELLS

Contents

1.0 INTRODUCTION

In the next few units we shall examine cell reproduction and the way in which they are differentiated according to the main functions which the cells perform in the body. This unit examines, in simple terms, what may be learnt of cell division and cell cycle.

2.0 A: OBJECTIVES

By the end of this unit, you should be able to:

- Outline the basic knowledge on cell division.
- Identify different parts of the cell and describe their functions.
- Explain differences between plant and animal cells

2.0 B: HOW TO STUDY THIS UNIT

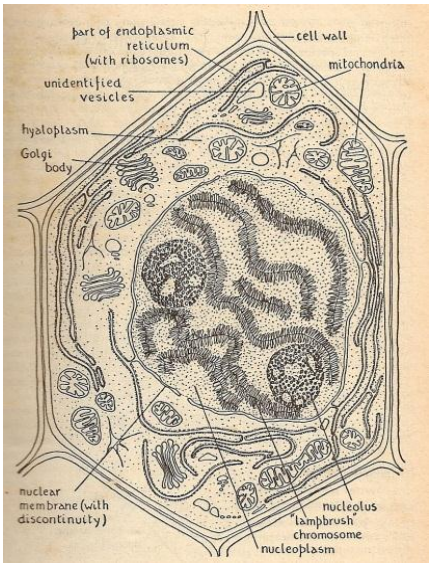
1. You are expected to read carefully through this unit twice before attempting to answer the activity questions. Do not look at the solution or guides provided at the end of the unit until you are satisfied that you have done your best to get all the answers.
2. Share your difficulties in understanding the unit with your mates, facilitators and by consulting other relevant materials or internet.
3. Ensure that you only check correct answers to the activities as a way of confirming what you have done.
4. Note that if you follow these instructions strictly, you will feel fulfilled at the end that you have achieved your aim and could stimulate you to do more.

3.0 MAIN CONTENTS

3.1 The Cell

Cell is the smallest unit of an organism that is able to function independently, the basic unit of living matter in all organisms, consisting of protoplasm enclosed within a cell membrane. All cells except bacterial cells have a distinct nucleus that contains the cell's DNA as well as other structures (called organelles) that include mitochondria (Fig. 5), the endoplasmic reticulum, and vacuoles. The main source of energy for all of a cell's biological processes is Adenosine triphosphate (ATP).

The elaboration of plant form and function depends on the ability of a plant cell to divide and differentiate. The decisions of individual cells to enter the cell cycle, maintain proliferation competence, become quiescent, expand, differentiate, or die depend on cell-to-cell communication and on the perception of various signals. These signals can include hormones, nutrients, light, temperature, and internal positional and developmental cues. In recent years, progress has been made in understanding the molecular control of plant pattern formation, especially in the model plant, *Arabidopsisthaliana*. Furthermore, specific genes have been found that are necessary for normal pattern formation and the control of the rates of cell division and differentiation. Cloning of these genes is revealing the molecular basis of plant pattern formation and the key players on plant signal transduction systems.



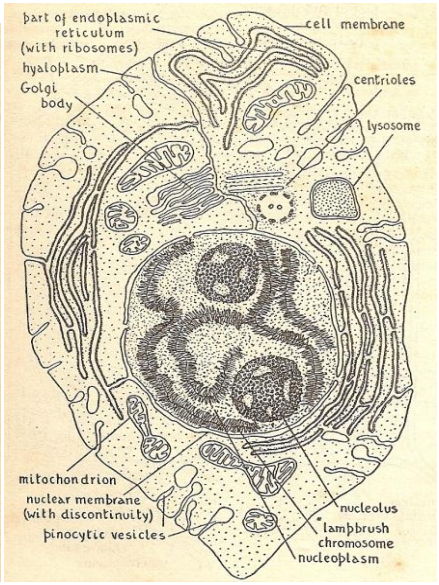


Fig. 4a Plant cellFig. 4b Structure of an animal cell

Table 1: Organelles and components of cells

Organelle	Location	Description	Functions
cell wall	in plants, absent in animal	*outer layer *rigid, strong, stiff *made of cellulose	*support (growth) *protection *allows water, oxygen, carbon-dioxide to pass into and out of cell
cell membrane	in both plant/animal	*plant - inside cell wall *animal - outer layer; cholesterol *selectively permeable	*support *protection *controls movement of materials in/out of cell *barrier between cell and its environment *maintains homeostasis
Nucleus	in both plant/animal	*large, oval	*controls cell activities
nuclear membrane	in both plant/animal	*surrounds nucleus *selectively permeable	*Controls movement of materials in/out of nucleus
Cytoplasm	in both plant/animal	*clear, thick, jellylike material and organelles found inside cell membrane	*supports /protects cell organelles
Endoplasmic reticulum (E.R.)	in both plant/animal	*network of tubes or membranes	*carries materials through cell
ribosome	in both plant/animal	*small bodies free or attached to E.R.	*produces proteins
Mitochondrion	in both plant/animal	*bean-shaped with inner membranes	*breaks down sugar molecules into energy
Vacuole	in plant - in few/large animals – (small)	*fluid-filled sacs	*store food, water, waste (plants need to store large amounts of food)
Lysosome	plant – (uncommon) animal – (common)	*small, round, with a membrane	*breaks down larger food molecules into smaller molecules *digests old cell parts

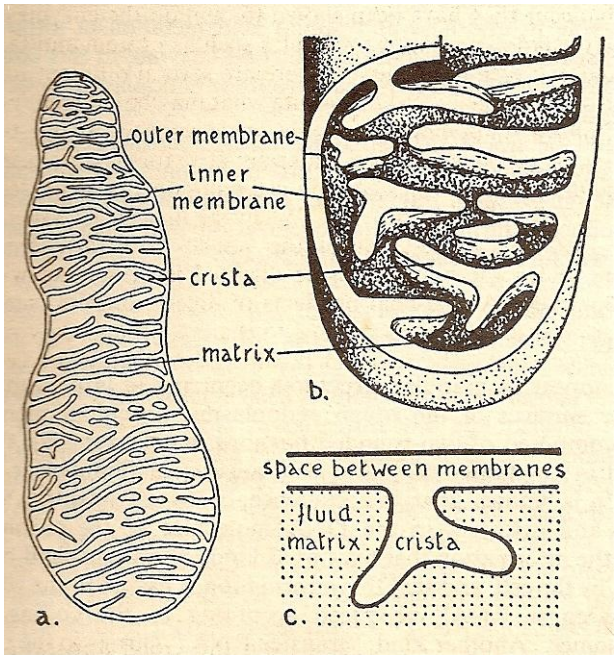


Fig. 5 Mitochondrion

(a) Natural appearance as seen with the electron microscope.
(b) and (c) Diagrams to show the arrangement of membranes, cristae and matrix.
Source: Plant and Animal Biology, Vol. 2, Vines and Rees

3.2 The Cell Cycle

Table 2 Phases of cell cycle

Cell cycle	
Interphase	G1 phase - S phase - G2 phase
M phase	Mitosis (Preprophase, Prophase, Prometaphase, Metaphase, Anaphase, Telophase) – Cytokinesis
Cell cycle checkpoints	Restriction point - Spindle checkpoint - Postreplication checkpoint
Other cellular phases	G0 phase – Apoptosis

These phases (Table 2) will be discussed in details under module 2 unit 2 that follows this unit.

Eukaryotic cells have a membrane-enclosed nucleus. Prokaryotic cells lack a true, membrane – delimited nucleus. Examples of prokaryotes are bacteria while other organisms – algae, fungi, protozoa, higher plants and animal are eukaryotes.

Despite the differences between prokaryotes and eukaryotes, there are several common features in their cell division processes. Replication of the DNA must occur. Segregation of the "original" and its "replica" follow. Whether the cell is eukaryotic or

prokaryotic, these basic events must occur. Cytokinesis is the process where one cell splits off from its sister cell and ends the cell division process. It usually occurs after cell division.

The Cell Cycle is the sequence of growth, DNA replication, growth and cell division that all cells go through. Beginning after cytokinesis, the daughter cells are quite small and low on ATP. They acquire ATP and increase in size during the (G1) phase of Interphase. Most cells are observed in Interphase, the longest part of the cell cycle.

After acquiring sufficient size and ATP, the cells then undergo DNA synthesis (replication of the original DNA molecules, making identical copies, one "new molecule" eventually destined for each new cell) which occurs during the S phase. Since the formation of new DNA is an energy draining process, the cell undergoes a second growth and energy acquisition stage, the G2 phase, a gap between DNA synthesis and mitotic cell division. The energy acquired during G2 is used in cell division (in this case mitosis). Regulation of the cell cycle is accomplished in several ways. Some cells divide rapidly (beans, for example take 19 hours for the complete cycle; red blood cells must divide at a rate of 2.5 million per second). Others, such as nerve cells, lose their capability to divide once they reach maturity. Some cells, such as liver cells, retain but do not normally utilize their capacity for division. Liver cells will divide if part of the liver is removed. The division continues until the liver reaches its former size.

Cancer cells are those which undergo a series of rapid divisions such that the daughter cells divide before they have reached "functional maturity". Environmental factors such as changes in temperature and pH, and declining nutrient levels lead to declining cell division rates. When cells stop dividing, they stop usually at a point late in the G1 phase, the R point (for restriction).

3.3 Cell division

Cell division is the process by which a cell divides to form two or more new cells. Upon completion of the process, each daughter cell contains the same genetic material as the original cell and roughly half of its cytoplasm.Among prokaryotes, cell division occurs by simple fission. Among eukaryotes, the cell nucleus divides first, and then a new cell membrane is formed between the nuclei to form the new cell. Cell division is used as a means of reproduction in organisms that reproduce asexually, as by fission or spore formation, and sexually reproducing organisms form gametes. Cell division is also the source of tissue growth and repair in multicellular organisms. The two types of cell division in eukaryotic organisms are mitosis and meiosis.

3.3.1 Prokaryotic Cell Division

Prokaryotes are much simpler in their organization than are eukaryotes. There are a great many more organelles in eukaryotes and also more chromosomes. The usual method of prokaryote cell division is termed binary fission, an example of asexual

reproduction. The prokaryotic chromosome is a single, simple DNA molecule that first replicates, then attaches each copy to a different part of the cell membrane. When the cell begins to pull apart, the replicate and original chromosomes are separated. Following cell splitting (cytokinesis), there are then two cells of identical genetic composition (except for the rare chance of a spontaneous mutation).

The prokaryote chromosome is much easier to manipulate than the eukaryotic one. We thus know much more about the location of genes and their control in prokaryotes. One consequence of this asexual method of reproduction is that all organisms in a colony are genetic equals. When treating a bacterial disease, a drug that kills one bacterium (of a specific type) will also kill all other members of that clone (colony) it comes in contact with. For example, *Escherichia coli*, a bacterium divides by binary division.

3.3.2 Eukaryotic Cell Division

Due to their increased numbers of chromosomes, organelles and complexity, eukaryote cell division in eukaryotes is more complicated, although the same processes of replication, segregation, and cytokinesis still occur.

4.0 Conclusion

The ATP is the source of energy for a cell while the sequence of growth, DNA replication and cell divisions are the major processes in cell cycle

5.0 Summary

In this unit we have learnt that:

- Cell division is the method by which a single cell divides to create two cells.
- There are two main types of cell division, mitosis and meiosis, in eukaryotes

6.0 Tutor Marked Assignment

Itemize the events involved in the cell cycle of a cell.

7.0 Further Reading and Other Resources

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K., & Walter, P. (2002).Mitosis.Molecular Biology of the Cell.Garland Science.

De Souza, C.P. & Osmani, S.A. (2007). "Mitosis, not just open or closed". *Eukaryotic Cell*, 6 (9): 1521–7.

Gubb, D. (1998).Cellular polarity, mitotic synchrony and axes of symmetry during growth. Where does the information come from? *Int. J. Dev. Bio*l. 42:369-377.

Lloyd, C. & Chan, J. (2006).Not so divided: the common basis of plant and animal cell division. Nature reviews. *Molecular Cell Biology* 7 (2): 147–52.

UNIT 2: CELL CIRCLE

Contents

1.0 INTRODUCTION

The unit examines a form of nuclear division in the eukaryotic cells because they are characterized by complex chromosome movement and exact chromosome duplication. This type of cell division is called mitosis.

2.0 A: OBJECTIVES

By the end of this unit, you should be able to:

- Observe the characteristics that distinguish each of the phases in the Cell Cycle.
- Diagrammatically illustrate Mitosis

2.0 B: HOW TO STUDY THIS UNIT

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3.0 MAIN CONTENTS

3.1 Sequence of Events in Cell cycle

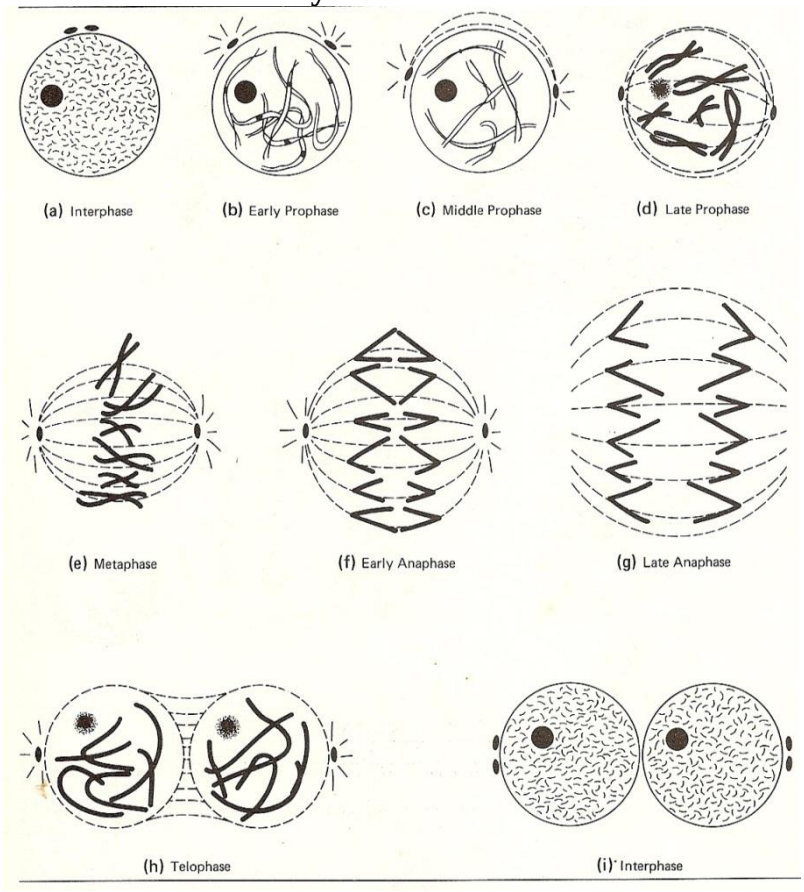


Fig. 6: Mitosis in an Animal Cell
(Source: Genetics, Ursula Goodenough, 1978, 2nd edition)

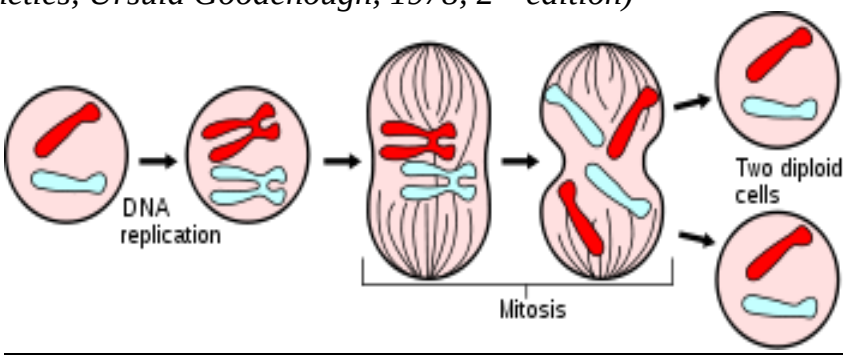


Fig. 7: Division of a parent cell into two daughter cells
(Source: Harl et al., 2002 Essential genetics)

Each turn of the cell cycle divides the chromosomes in a cell nucleus.
The cell cycle, or cell-division cycle, is the series of events that take place in a cell leading to its division and duplication (replication). In cells without a nuclear membrane (prokaryotes), the cell cycle occurs via a process termed binary fission. In cells with a nucleus (eukaryotes), the cell cycle can be divided in two brief periods: interphase—during which the cell grows, accumulating nutrients needed for mitosis

and duplicating its DNA—and the mitosis (M) phase, during which the cell splits itself into two distinct cells, often called "daughter cells". The cell cycle is a vital process for both reproductive and vegetative cells development. A single-celled fertilized cell (egg) develops into a mature organism while hair, skin, and blood cells are renewed as vegetative cells.

3.2 The Phases

The cell cycle consists of five distinct phases: G0, G1 phase, S phase (synthesis), G2 phase (collectively known as interphase) and M phase (mitosis). M phase is itself composed of two tightly coupled processes: karyokinesis, in which the cell's chromosomes are divided between the two daughter cells, and cytokinesis, in which the cell's cytoplasm divides forming distinct cells. Activation of each phase is dependent on the proper progression and completion of the previous one. Cells that have temporarily or reversibly stopped dividing are said to have entered a state of quiescence called G0 phase (Table 3).

Table 3: The Five Phases of Cell Cycle

State	Phase	Abbreviation	Description
quiescent/ senescent	Gap 0	G0	A resting phase where the cell has left the cycle and has stopped dividing.
Interphase	Gap 1	G1	Cells increase in size in Gap 1. The G1 checkpoint control mechanism ensures that everything is ready for DNA synthesis.
	Synthesis	S	DNA replication occurs during this phase.
	Gap 2	G2	During the gap between DNA synthesis and mitosis, the cell will continue to grow. The G2 checkpoint control mechanism ensures that everything is ready to enter the M (mitosis) phase and divide.
Cell division	Mitosis	M	Cell growth stops at this stage and cellular energy is focused on the orderly division into two daughter cells. A checkpoint in the middle of mitosis (Metaphase Checkpoint) ensures that the cell is ready to complete cell division.

(Source: Vines and Rees, Plant and Animal Biology, Vol. 2).

After cell division, each of the daughter cells begins the interphase of a new cycle. Although the various stages of interphase are not usually morphologically distinguishable, each phase of the cell cycle has a distinct set of specialized biochemical processes that prepare the cell for initiation of cell division.

3.2.1 Resting (G0 phase)

The following are the summary of events in mitotic cell division (Fig. 6 to 7 and Table 2). The term "post-mitotic" is sometimes used to refer to both quiescent and senescent

cells. Non proliferative cells in multicellular eukaryotes generally enter the quiescent G0 state from G1 and may remain quiescent for long periods of time, possibly indefinitely (as is often the case for neurons). This is very common for cells that are fully differentiated. Cellular senescence is a state that occurs in response to DNA damage or degradation that would make a cell's progeny (offspring) nonviable. It is often a biochemical alternative to the self-destruction of such a damaged cell by apoptosis (programmed cell death).

3.2.2 Interphase

The interphase can be divided into three phases – G1, S and G2

G1 phase

This is the first phase within interphase, from the end of the previous M phase until the beginning of DNA synthesis which is termed the G1 (G indicating gap). During this phase, the biosynthetic activities of the cell, which had been considerably slowed down during M phase, resume at a high rate. This phase is marked by synthesis of various enzymes that are required in S phase, mainly those needed for DNA replication. Duration of G1 is highly variable, even among different cells of the same species.

S phase

The ensuing S phase starts when DNA synthesis commences; when the synthesis is complete, all of the chromosomes have been replicated, i.e., each chromosome has two (sister) chromatids. Thus, during this phase, the amount of DNA in the cell has effectively doubled, though the ploidy, basic number of chromosomes of the cell remains the same. Rates of RNA transcription and protein synthesis are very low during this phase. An exception to this is histone production, most of which occurs during the S phase.

G2 phase

The cell then enters the G2 phase, which lasts until the cell enters mitosis. Again, significant protein synthesis occurs during this phase, mainly involving the production of microtubules, which are required during the process of mitosis. Inhibition of protein synthesis during G2 phase prevents the cell from undergoing mitosis.

3.2.3 M Phase

This phase involves the mitotic cell division. The relatively brief M phase consists of nuclear division (karyokinesis) and cytoplasmic division (cytokinesis). In plants and algae, cytokinesis is accompanied by the formation of a new cell wall.

The M phase has been broken down into several distinct phases, sequentially known as prophase, prometaphase, metaphase, anaphase and telophase leading to cytokinesis (Fig. 6b-h).

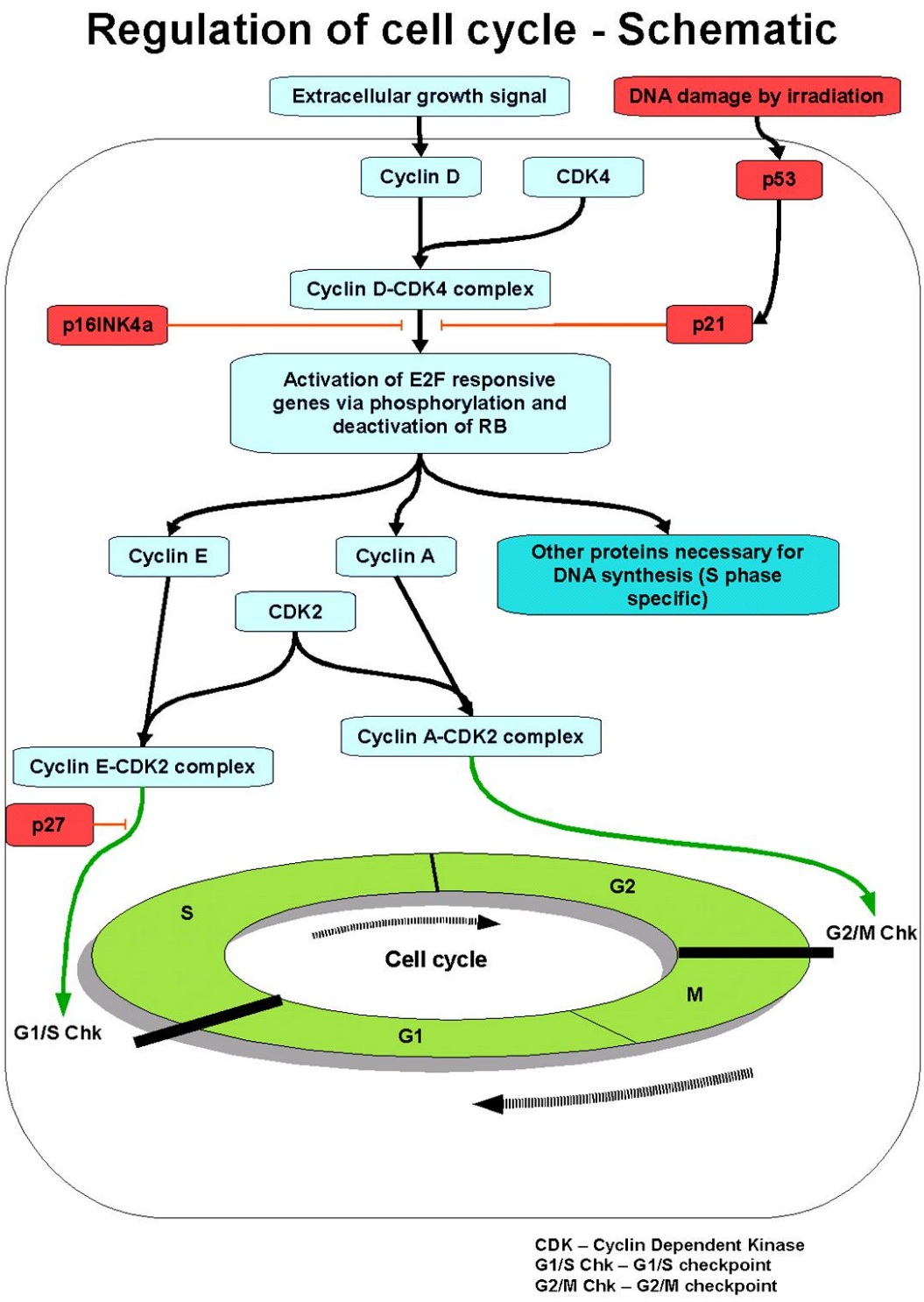
Mitosis is the process in which a eukaryotic cell separates the chromosomes in its cell nucleus into two identical sets in two daughter nuclei. It is generally followed immediately by cytokinesis, which divides the nuclei, cytoplasm, organelles and cell membrane into two daughter cells containing roughly equal shares of these cellular components. karyokinesis and cytokinesis together define the M phase of the cell cycle - the division of the mother cell into two daughter cells, genetically identical to each other and to their parent cell.

Mitosis occurs exclusively in eukaryotic cells, but occurs in different ways in different species. For example, animals undergo an "open" mitosis, where the nuclear envelope breaks down before the chromosomes separate, while fungi such as *Aspergillusnidulans* and *Saccharomyces cerevisiae* (yeast) undergo a "closed" mitosis, where chromosomes divide within an intact nuclear membrane. Prokaryotic cells, which lack a nuclear membrane, divide by a process called binary fission.

The process of mitosis is complex and highly regulated. During the process of mitosis the pairs of chromosomes condense and attach to fibers that pull the sister chromatids to opposite sides of the cell. The cell then divides during cytokinesis, to produce two identical daughter cells.

Because cytokinesis usually occurs in conjunction with mitosis, "mitosis" is often used interchangeably with "mitotic phase". However, there are many cells where karyokinesis and cytokinesis occur separately, forming single cells with multiple nuclei. This occurs most notably among the fungi and slime moulds, but is found in various different groups. Even in animals, cytokinesis and karyokinesis may occur independently, for instance during certain stages of fruit fly embryonic development. Errors in mitosis can either kill a cell through apoptosis or cause mutations that may lead to cancer.

3.3 Regulation of eukaryotic cell cycle



Explain this diagram briefly.

Fig. 8: Schematic diagram of the regulation of cell cycle
(Source: McGowan 2003, Progress in cell cycle, vol. 5)

Regulation of the cell cycle involves processes crucial to the survival of a cell, including the detection and repair of genetic damage as well as the prevention of uncontrolled cell division. The molecular events that control the cell cycle are ordered

and directional; that is, each process occurs in a sequential fashion and it is impossible to "reverse" the cycle.

Cyclin is any of several related proteins whose concentrations rise and fall during the course of the eukaryotic cell cycle. Cyclins form complexes with cyclin-dependent kinases, thereby activating and determining the substrate specificity of these enzymes

NOTE: We shall not dwell much on the regulation of cell cycle as it is beyond the scope of this introductory course.

4.0 CONCLUSION

Karyokinesis and cytokinesis are cellular processes interwoven and are highly regulated within the cells.

5.0 SUMMARY

In this unit we have learnt that:

- The cell cycle consists of five distinct phases:
- Mitosis occurs exclusively in eukaryotic cells, but occurs in different ways in different species.
- The stages of mitosis proper are prophase, prometaphase, metaphase, anaphase and telophase.

6.0 TUTOR MARKED ASSIGNMENT

The cell cycle consists of five distinct phases, expatiate.

7.0 FURTHER READING AND OTHER RESOURCES

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K. & Walter, P. (2002).Chapter 17. Molecular Biology of the Cell (4th ed.). New York: Garland Science. ISBN 0-8153-3218-1.

Krieger, M., Scott, M.P.; Matsudaira, P.T., Lodish, H.F., Darnell, J.E., Zipursky, L., Kaiser, C.; Berk, A. (2004).*Molecular Cell Biology*.New York: W.H. Freeman and CO. ISBN 0-7167-4366-3.

Morgan, D.L. (2007). The Cell Cycle: Principles of Control. London: Published by New Science Press in association with Oxford University Press. ISBN 0-87893-508-8.

Smith, J.A. & Martin, L. (1973).Do Cells Cycle? Proceedings of the National Academy of Sciences, U.S.A. 70 (4): 1263–1267.

UNIT 3: PHASES OF CELL CYCLE (MITOSIS)

Contents

1.0 INTRODUCTION

In the last unit, we discussed mainly the phases associated with karyokinesis and cytokinesis in mitosis. In this unit, we shall look at mitosis in details, the processes following DNA replication in a eukaryotic cell, and its importance for the maintenance of the chromosomal set. Do you now remember that mitosis consists of two sets of processes – karyokinesis and cytokinesis?

2.0 A: OBJECTIVES

By the end of this unit, you should be able to:

- Identify each phase of the cell cycle, leading to mitotic cell division.
- Discuss these phases using diagrams.

2.0 B: HOW TO STUDY THIS UNIT

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3.0 MAIN CONTENTS

3.1 A Review of Mitosis

Mitosis is the process of forming identical daughter cells by replicating and dividing the original chromosomes, in effect making a cellular duplicate. Mitosis deals with the segregation of the chromosomes and organelles into daughter cells. Eukaryotic chromosomes occur in the cell in greater numbers than prokaryotic chromosomes. The condensed replicated chromosomes have several points of interest. Replicated chromosomes consist of two molecules of DNA (along with their associated histone proteins) known as chromatids. The area where both chromatids are in contact with each other is known as the centromeres. The kinetochores (where microtubules of the spindle apparatus attach) are on the outer sides of the centromere. Remember that chromosomes are condensed chromatin (DNA plus histone proteins).

You should also not forget that during mitosis replicated chromosomes are positioned near the middle of the cytoplasm and then segregated so that each daughter cell receives a copy of the original DNA (if you start with 46 in the parent cell, you should end up with 46 chromosomes in each daughter cell). To do this, cells utilize microtubules (referred to as the spindle apparatus) to "pull" chromosomes into each "cell". Animal cells (except for a group of worms known as nematodes) have a centriole. Plants and most other eukaryotic organisms lack centrioles. Prokaryotes, of course, lack spindles and centrioles; the cell membrane assumes this function when it pulls the by-then replicated chromosomes apart during binary fission. Cells that contain centrioles also have a series of smaller microtubules, the aster, that extend from the centrioles to the cell membrane. The aster is thought to serve as a brace for the functioning of the spindle fibers. The phases of mitosis are sometimes difficult to separate. Remember that the process is a dynamic one, not the static process displayed of necessity in a textbook.

3.2 An Overview of Events in cells After Mitosis

Please be reminded that mitosis is made up of two different processes – karyokinesis and cytokinesis. The following events describe karyokinesis. The primary result of mitosis is the division of the parent cell's genome (full set of gene) into two daughter cells. The genome is composed of a number of chromosomes - complexes of tightly-coiled DNA that contain genetic information vital for proper cell function. Because each resultant daughter cell should be genetically identical to the parent cell, the parent cell must make a copy of each chromosome before mitosis. This occurs during S phase, in interphase, the period that precedes the mitotic phase in the cell cycle where preparation for mitosis occurs.

Each new chromosome now contains two identical copies of itself, called sister chromatids, attached together in a specialized region of the chromosome known as the

centromere. Each sister chromatid is not considered a chromosome in itself, and a chromosome does not always contain two sister chromatids. This is because in most eukaryotes, the nuclear envelope that separates the DNA from the cytoplasm disassembles. The chromosomes align themselves in a line spanning the cell. Microtubules, essentially miniature strings, splay (spread) out from opposite ends of the cell and shorten, pulling apart the sister chromatids of each chromosome. As a matter of convention, each sister chromatid is now considered a chromosome, so they are renamed to sister chromosomes. As the cell elongates, corresponding sister chromosomes are pulled toward opposite ends. A new nuclear envelope forms around the separated sister chromosomes.

After karyokinesis cytokinesis is well underway. In animal cells, the cell pinches inward where the imaginary line used to be (the pinching of the cell membrane to form the two daughter cells is called cleavage furrow), separating the two developing nuclei. In plant cells, the daughter cells will construct a new dividing cell wall (called cell plate) between each other. Eventually, the mother cell will be split in half, giving rise to two daughter cells, each with an equivalent and complete copy of the original genome.

Prokaryotic cells undergo a process similar to mitosis called binary fission. However, prokaryotes cannot be properly said to undergo mitosis because they lack a nucleus and only have a single chromosome with no centromere. The next few pages (3.2.1 – 3.2.7) will discuss the proper nucleus events leading to karyokinesis which can be regarded as the major process in mitosis.

3.2.1 Interphase

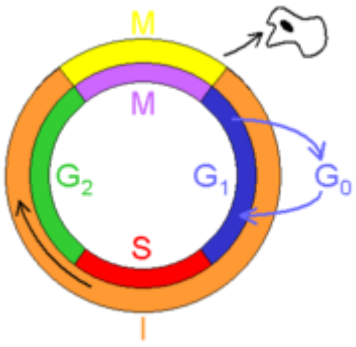


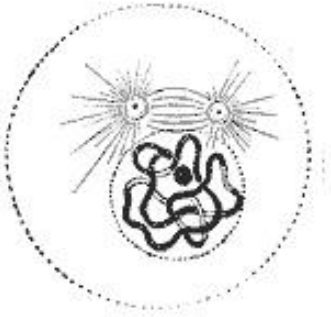
Fig. 9 The cell cycle
(Source: The Biology Project, Univ. of Arizona, 1997).

The mitotic phase (mitosis) is a relatively short period of the cell cycle. It alternates with the much longer interphase, where the cell prepares itself for cell division. Interphase is therefore not part of mitosis. Interphase is divided into three phases, G1 (first gap), S (synthesis), and G2 (second gap). During all three phases, the cell grows by producing proteins and cytoplasmic organelles. However, chromosomes are replicated only during the S phase. Thus, a cell grows (G1), continues to grow as it

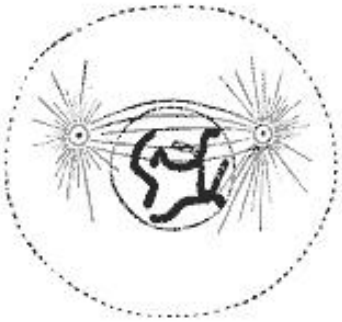
duplicates its chromosomes (S), grows more and prepares for mitosis (G2), and finally divides (M) before restarting the cycle.

3.2.2 Preprophase

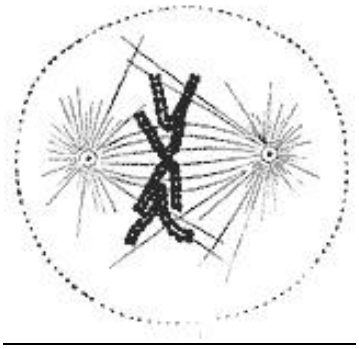
In plant cells only, prophase is preceded by a pre-prophase stage. In highly vacuolated plant cells, the nucleus has to migrate into the center of the cell before mitosis can begin. This is achieved through the formation of a phragmosome, a transverse sheet of cytoplasm that bisects the cell along the future plane of cell division. In addition to phragmosome formation, preprophase is characterized by the formation of a ring of microtubules and actin filaments (called preprophase band) underneath the plasma membrane around the equatorial plane of the future mitotic spindle. This band marks the position where the cell will eventually divide. The cells of higher plants (such as the flowering plants) lack centrioles: with microtubules forming a spindle on the surface of the nucleus and then being organized into a spindle by the chromosomes themselves, after the nuclear membrane breaks down. The preprophase band disappears during nuclear envelope disassembly and spindle formation in prometaphase.



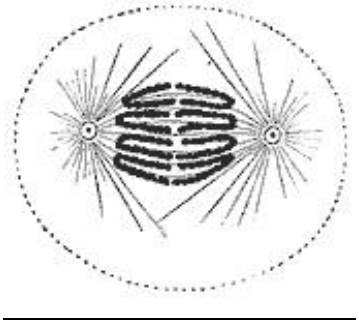
(a) Prophase: The two round objects above the nucleus are the centrosomes. The chromatin has condensed.



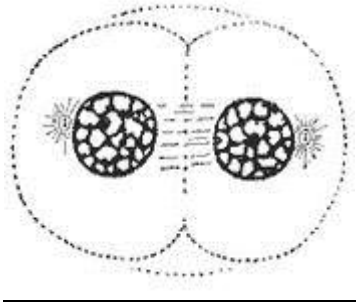
(b) Prometaphase: The nuclear membrane has degraded, and microtubules have invaded the nuclear space. These microtubules can attach to kinetochores or they can interact with opposing microtubules.



(c) Metaphase: The chromosomes have aligned at the metaphase plate.



(d) Early anaphase: Kinetochore microtubules shorten.



(e) Telophase: The decondensing chromosomes are surrounded by nuclear membranes. Note cytokinesis has already begun, the pinching is known as the cleavage furrow.

Fig. 10 Stages of mitosis (a) Prophase, (b) Prometaphase, (c) Metaphase, (d) Early Anaphase, (e) Telophase.
(Source: Ursula Goodenough, 1978, Genetic, 2nd edition)

3.2.3 Prophase

Prophase is the first stage of mitosis proper. Chromatin condenses (remember that the replica chromosomes replicate to chromatins during Interphase), the nuclear envelope dissolves, centrioles (if present) divide and migrate, kinetochores and kinetochore fibers form, and the spindle forms.

Normally, the genetic material in the nucleus is in a loosely bundled coil called chromatin. At the onset of prophase, chromatin condenses together into a highly ordered structure called a chromosome. Since the genetic material has already been

duplicated earlier in S phase, each replicated chromosome has two sister chromatids, bound together at the centromere by the cohesion complex. Chromosomes are visible at high magnification through a light microscope.

Close to the nuclear envelop are structures called centrosomes, which are made of a pair of centrioles. The centrosome is the coordinating center for the cell's microtubules. A cell inherits a single centrosome at cell division, which replicates before a new mitosis begin, giving a pair of centrosomes. The two centrosomes nucleate microtubules (which may be regarded as cellular ropes or poles) to form the spindle by polymerizing soluble tubulin. Molecular motor proteins then push the centrosomes along these microtubules to opposite side of the cell. Although centrosomes help organize microtubule assembly, they are not essential for the formation of the spindle, since they are absent from plants, and centrosomes are not always used in meiosis, the cell division in reproductive cells.

3.2.4 Prometaphase

The nuclear envelope disassembles and microtubules invade the nuclear space. This is called open mitosis, and it occurs in most multicellular organisms. Fungi and some protists, such as algae or trichomonads, undergo a variation called closed mitosis where the spindle forms inside the nucleus or its microtubules are able to penetrate an intact nuclear envelope.

Each chromosome forms two kinetochores at the centromere, one attached at each chromatid. A kinetochore is a complex protein structure that is analogous to a ring for the microtubule hook; it is the point where microtubules attach themselves to the chromosome. Although the kinetochore structure and function are not fully understood, it is known that it contains some form of molecular motor. When a microtubule connects with the kinetochore, the motor activates, using energy from ATP to "crawl" up the tube toward the originating centrosome. This motor activity, coupled with polymerisation and depolymerisation of microtubules, provides the pulling force necessary to later separate the chromosome's two chromatids.

When the spindle grows to sufficient length, kinetochore microtubules begin searching for kinetochores to attach to. A number of nonkinetochore microtubules find and interact with corresponding nonkinetochore microtubules from the opposite centrosome to form the mitotic spindle. Prometaphase is sometimes considered as part of prophase.

3.2.5 Metaphase

Metaphase follows Prophase. The chromosomes (which at this point consist of chromatids held together by a centromere) migrate to the equator of the spindle, where the spindles attach to the kinetochore fibers.

As microtubules find and attach to kinetochores in prometaphase, the centromeres of the chromosomes convene along the metaphase plate or equatorial plane, an imaginary

line that is equidistant from the two centrosome poles. This even alignment is due to the counterbalance of the pulling powers generated by the opposing kinetochores, analogous to a tug-of-war between people of equal strength. In certain types of cells, chromosomes do not line up at the metaphase plate and instead move back and forth between the poles randomly, only roughly lining up along the midline. Metaphase means "after."

Because proper chromosome separation requires that every kinetochore be attached to a bundle of microtubules (spindle fibres), it is thought that unattached kinetochores generate a signal to prevent premature progression to anaphase without all chromosomes being aligned. The signal creates the mitotic spindle checkpoint.

3.2.6 Anaphase

Anaphase begins with the separation of the centromeres, and the pulling of chromosomes (we call them chromosomes after the centromeres are separated) to opposite poles of the spindle.

When every kinetochore is attached to a cluster of microtubules and the chromosomes have lined up along the metaphase plate, the cell proceeds to anaphase.

Two events then occur; first, the proteins that bind sister chromatids together are cleaved, allowing them to separate. These sister chromatids, which have now become distinct sister chromosomes, are pulled apart by shortening kinetochore microtubules and move toward the respective centrosomes to which they are attached. Next, the nonkinetochore microtubules elongate, pushing the centrosomes (and the set of chromosomes to which they are attached) apart to opposite ends of the cell. The force that causes the centrosomes to move towards the ends of the cell is still unknown, although there is a theory that suggests that the rapid assembly and breakdown of microtubules may cause this movement.

These two stages are sometimes called early and late anaphase. Early anaphase is usually defined as the separation of the sister chromatids, while late anaphase is the elongation of the microtubules and the microtubules being pulled farther apart.
At the end of anaphase, the cell has succeeded in separating identical copies of the genetic material into two distinct populations.

3.2.7 Telophase

Telophase (means "end") is a reversal of prophase and prometaphase events. It "cleans up" the after effects of mitosis. At telophase, the nonkinetochore microtubules continue to lengthen, elongating the cell even more. Corresponding sister chromosomes attach at opposite ends of the cell. A new nuclear envelope, using fragments of the parent cell's nuclear membrane, forms around each set of separated sister chromosomes. Both sets of chromosomes, now surrounded by new nuclear envelopes, unfold back into chromatin. Mitosis is complete, but cell division is not yet complete.

Telophase is when the chromosomes reach the poles of their respective spindles, the nuclear envelope reforms, chromosomes uncoil into chromatin form, and the nucleolus (which had disappeared during Prophase) reform. Where there was one cell there are now two smaller cells each with exactly the same genetic information. These cells may then develop into different mature forms via the processes of development.

3.3. Cytokinesis

Cytokinesis is the second process involved in cell division. It is the process of splitting the daughter cells apart. Whereas mitosis (karyokinesis) is the division of the nucleus, cytokinesis is the splitting of the cytoplasm and allocation of the golgi, plastids and cytoplasm into each new cell.

Cytokinesis is often mistakenly thought to be the final part of telophase; however, cytokinesis is a separate process that begins at the same time as telophase. Cytokinesis is technically not even a phase of mitosis, but rather a separate process, necessary for completing cell division. In animal cells, a cleavage furrow (pinch) containing a contractile ring develops where the metaphase plate used to be, pinching off the separated nuclei. In both animal and plant cells, cell division is also driven by vesicles derived from the Golgi apparatus, which move along microtubules to the middle of the cell. In plants this structure coalesces into a cell plate at the center of the phragmoplast and develops into a cell wall, separating the two nuclei. The phragmoplast (Fig. 11) is a microtubule structure typical for higher plants, whereas some green algae use a phycoplast microtubule array during cytokinesis. Each daughter cell has a complete copy of the genome of its parent cell. The end of cytokinesis marks the end of the M-phase.

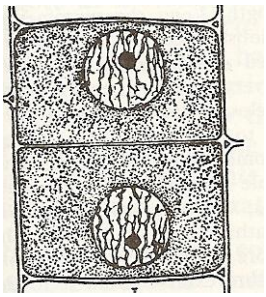


*Fig. 11.*Plant cytokinesis
(Source: Botany for degree students, Dutta A.C., 5th edition, 1963).

3.4 Significance of Mitosis

Please note that mitosis occurs in reproductive and vegetative cells. Mitosis is important for the maintenance of the chromosomal set; each cell formed receives chromosomes that are alike in composition and equal in number to the chromosomes of the parent cell. Transcription is generally believed to cease during mitosis, but epigenetic mechanisms such as bookmarking function during this stage of the cell cycle to ensure that the "memory" of which genes were active prior to entry into mitosis are transmitted to the daughter cells.

Mitosis occurs immediately after meiosis in reproductive cells. Although errors in mitosis are rare, the process may go wrong, especially during early cellular divisions in the zygote. Mitotic errors can be especially dangerous to the organism because future offspring from this parent cell will carry the same disorder.

In non-disjunction, a chromosome may fail to separate during anaphase. One daughter cell will receive both sister chromosomes and the other will receive none. This results in the former cell having three chromosomes containing the same genes (two sisters and a homologue), a condition known as trisomy, and the latter cell having only one chromosome (the homologous chromosome), a condition known as monosomy. These cells are considered aneuploid, a condition often associated with cancer.

Mitosis is a traumatic process. The cell goes through dramatic changes in ultrastructure, its organelles disintegrate and reform in a matter of hours, and chromosomes are jostled constantly by probing microtubules. Occasionally, chromosomes may become damaged. An arm of the chromosome may be broken and the fragment lost, causing **deletion**. The fragment may incorrectly reattach to another, non-homologous chromosome, causing **translocation**. It may reattach to the original chromosome, but in reverse orientation, causing **inversion**. Or, it may be treated erroneously as a separate chromosome, causing **chromosomal duplication**. The effect of these genetic abnormalities depends on the specific nature of the error. It may range from no noticeable effect to cancer induction or organism death.

4.0 CONCLUSION

It is important to emphasize that mitosis is well defined in eukaryotic cells while prokaryotic cells cannot be said to undergo proper mitosis because they do not have a well defined nucleus.

5.0 SUMMARY

In this unit we have learnt that:

- The karyokinesis and cytokinesis are cycle of changes that take place before in a parent cell
- These changes lead to the single parent cell dividing into two daughter cells during mitosis
- Mitosis occurs both in reproductive and vegetative cells
- Mitosis is very important in several aspect of the cell and its constituents

6.0 TUTOR MARKED ASSIGNMENT

Discuss the five distinct phases of the cell cycle using diagrammes

Distinguish between karyokinesis and cytokinesis. List characteristic features of each phase of the cell cycle.

7.0 FURTHER READING AND OTHER RESOURCES

Lodish, H., Berk, A., Zipursky, L., Matsudaira, P., Baltimore, D. &Darnell, J. (2000)."Overview of the Cell Cycle and Its Control".Molecular Cell Biology. W.H. Freeman.

Morgan, D. L. (2007). The Cell Cycle: Principles of control. London: Published by New Science Press in association with Oxford University Press. ISBN 0-9539181-2-2.

Campbell, N,.& Reece, J. (2001). "The Cell Cycle". Biology (6th ed.). San Francisco: Benjamin Cummings/Addison-Wesley. ISBN 0-8053-6624-5.

UNIT 4: CELL GROWTH

Contents

1.0 INTRODUCTION

The term cell growth is used in the contexts of cell development and cell division. When used in the context of cell division, it refers to growth of cell populations, where one cell (the "mother cell") grows to maturity and divides to produce two "daughter cells". This unit describes in details the meaning of cell growth.

2.0 A: OBJECTIVES

By the end of this unit, you should be able to:

- Define cell growth;
- Distinguish between normal cell growth and cell growth disorder;
- Describe cell number, cell population and cell size.

2.0 B: HOW TO STUDY THIS UNIT

1. You are expected to read carefully through this unit twice before attempting to answer the activity questions. Do not look at the solution or guides provided at the end of the unit until you are satisfied that you have done your best to get all the answers.
2. Share your difficulties in understanding the unit with your mates, facilitators and by consulting other relevant materials or internet.
3. Ensure that you only check correct answers to the activities as a way of confirming what you have done.
4. Note that if you follow these instructions strictly, you will feel fulfilled at the end that you have achieved your aim and could stimulate you to do more.

3.0 MAIN CONTENTS

3.1 Cellular Growth

In most cases, living things grow by producing more cells. There are two main reasons why cells divide: (1) The larger a cell gets, the more demands it places on its DNA. (2) As a cell gets bigger, it has more work moving enough nutrients (food) and wastes across its cell membrane. The rates at which materials move through the cell membrane depend on the cell's surface area – the total area of its cell membrane. However, the rate at which food and oxygen are used up and formation of waste products depends on the cell's volume.

As a cell grows, its internal volume increases faster than its surface area. That is, as a cell becomes bigger, its ratio of surface area to volume decreases. Before a cell gets too large, it divides, forming two "daughter" cells. Cell division is the process by which a cell divides into two new daughter cells

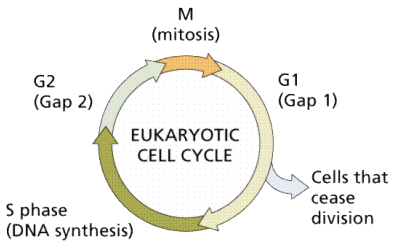


Fig. 12 Eukaryotic cell cycle

(Source: The American Heritage® Dictionary of the English Language, Fourth Edition copyright ©2000 by Houghton Mifflin Company).

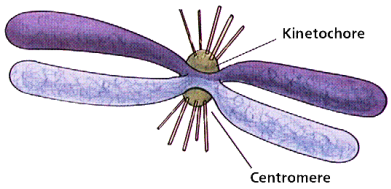


Fig. 13. Structure of eukaryotic chromosome
(Source: The American Heritage® Dictionary of the English Language, Fourth Edition copyright ©2000 by Houghton Mifflin Company).

Cytokinesis usually occurs at the same time as telophase. In animal cells, the cell membrane pinches the cytoplasm into two equal parts: Centromere and sister chromatids. Cenromeres are regions that provide an attachment site for the spindle fibers that pull the pairs of homologous chromosomes apart during mitosis (Fig. 13), Can you still remember what we discussed in unit 3?.

3.2 Cellular differentiation

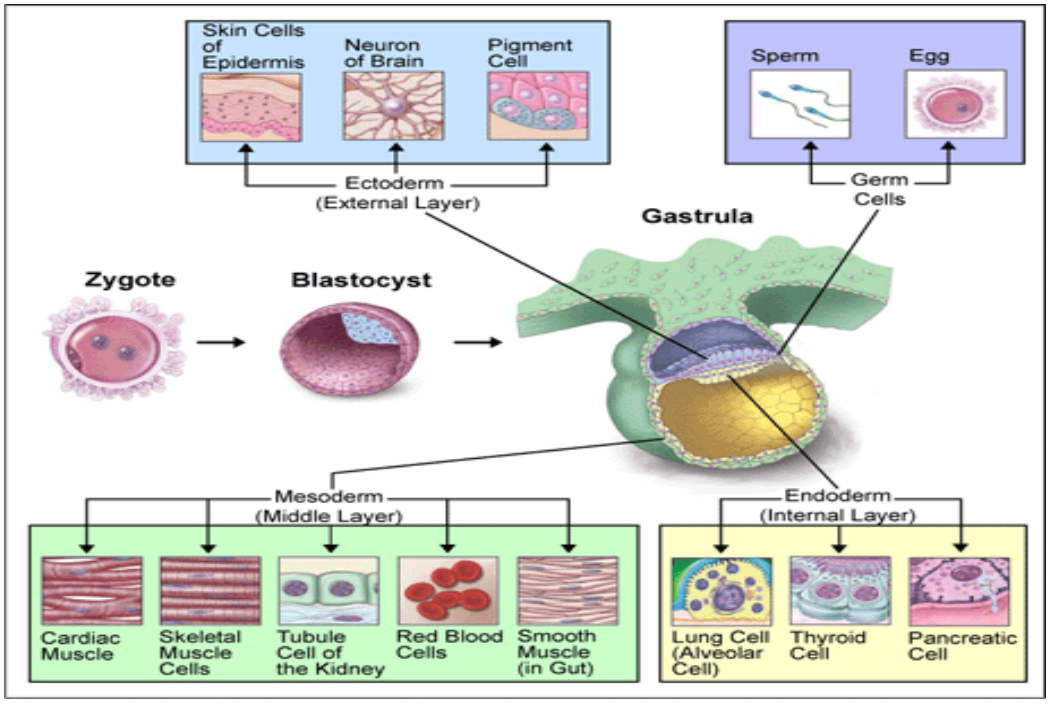


Figure 14 Cellular differentiation
In the center of the diagram the early steps in the development of a mammal. On the top and bottom are some of the fully-differentiated cell types that will eventually form in the adult.

Let us consider the example of the development of a mammal (Fig. 14). The fertilized egg (zygote) differentiates into the blastocyst (early embryo) and this differentiates to

the gastrula (late embryo). Later ectoderm, germ cells, mesoderm and endoderm all develop, form different cell types. Each type then differentiates into specialized cell, divides and form tissues. In developmental biology, cellular differentiation is the process by which a less specialized cell becomes a more specialized cell type. Differentiation occurs numerous times during the development of a multicellular organism as the organism changes from a single zygote to a complex system of tissues and cell types (Fig. 14). Differentiation is a common process in adults as well: adult stem cells divide and create fully-differentiated daughter cells during tissue repair and during normal cell turnover. Differentiation dramatically changes a cell's size, shape, membrane potential, metabolic activity, and responsiveness to signals. These changes are largely due to highly-controlled modifications in gene expression. With a few exceptions, cellular differentiation almost never involves a change in the DNA sequence itself. Thus, different cells can have very different physical characteristics despite having the same genome.

3.3 Cell Turnover

In higher vertebrates (birds and mammals), adult body size is relatively constant as compared with its size of organs. Nevertheless, in many tissues, cell birth continues throughout their life - thus, for body and organ size to remain stable, cells must also die. Cell number is therefore proportional to the rate of cell proliferation and the rate of cell death.

3.3.1 Renewing cells

Mitosis is the process that brings about the renewing of cells. In most adult tissues, cell turnover continues throughout the animal's lifespan. In some tissues, cell turnover is very slow, and cell proliferation occurs primarily after injury - e.g., liver, blood vessels. In some adult tissues, cell turnover is rapid and occurs via the stem cells (a). hemopoietic system, (b). intestinal mucosa, and (c). skin epidermis

3.3.2 Cell number

In higher vertebrates cell birth continues throughout life. However, for body and organ size to remain stable, cells must also die. Cell number is therefore proportional to the rate of cell proliferation and the rate of cell death. The processes of cell birth and cell death are termed cell turnover.

3.3.3 Cell populations

Cell populations go through a type of exponential growth called doubling. Thus, each generation of cells should be twice as numerous as the previous generation. However, the number of generations only gives a maximum figure as not all cells survive in each generation. Cell divisions bring about population of cells. For example, during mitosis, a parent cell divides to give two daughter cells (Fig 15).

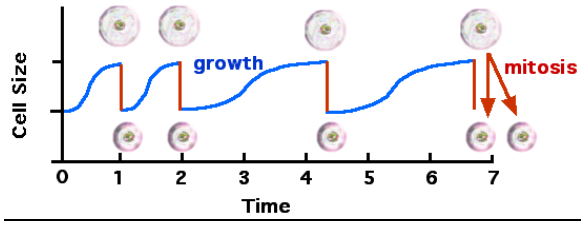


Fig. 15 Cell size
(Source: Copyright © 2009 Answers Corporation)

3.3.4 Cell size regulation in mammals

The cell size in mammals is regulated based on certain factors. Many of the signal molecules that convey information to cells during the control of cellular differentiation or growth are called growth factors. The protein that regulates translation and cell division is influenced by nutrient availability so that when cells are not able to grow to normal size they will not undergo cell division. For example, the size of post-mitotic neurons depends on the size of the cell body, axon and dendrites.

In vertebrates, neuron size is often a reflection of the number of synaptic contacts onto the neuron or from a neuron onto other cells. For example, the size of motor neurons usually reflects the size of the motor unit that is controlled by the motor neuron. Invertebrates often have giant neurons and axons that provide special functions such as rapid action potential propagation. Mammals also use this trick for increasing the speed of signals in the nervous system.

3.4 Types of Cell division

For most of the constituents of the cell, growth is a steady, continuous process, interrupted only briefly at M phase when the nucleus and the cell divides to two. The process of cell division (e.g mitosis), called cell cycle, has four major parts called phases. The first part, called G1 phase is marked by synthesis of various enzymes that are required for DNA replication. The second stage of the cell cycle is the S phase, where DNA replication produces two identical sets of chromosomes. The third part is the G2 phase where significant protein synthesis occurs. During this phase, it involves the production of microtubules, which are required during the process of division,

called mitosis. The fourth stage, M phase, consists of nuclear division (karyokinesis) and cytoplasmic division (cytokinesis), accompanied by the formation of a new cell membrane. This is the physical division of "mother" and "daughter" cells. The M phase has been broken down into several distinct subphases, sequentially known as prophase, prometaphase, metaphase, anaphase and telophase leading to cytokinesis (Fig. 9, unit 3).
Cell division is more complex in eukaryotes than in other organisms. Prokaryotic cells such as bacterial cells reproduce by binary fission, a process that includes DNA replication, chromosome segregation, and cytokinesis. Eukaryotic cell division either involves mitosis or a more complex process called meiosis. Mitosis and meiosis are sometimes called the two "nuclear division" processes. Binary fission is similar to eukaryotic cell division that involves mitosis. Both lead to the production of two daughter cells with the same number of chromosomes as the parental cell. Meiosis (a reduction division) is used for a special cell production process of diploid organisms. It produces four special daughter cells (gametes) each having half the normal cellular amount of DNA. A male and a female gamete can then combine to produce a fertilized cell now having normal amount of chromosomes.

A cell must copy its genetic information before cell division begins. Each daughter cell then gets a complete copy of that information after cell division. In most prokaryotes, the cell division is a simple matter of separating the contents of the cell into two parts. In eukaryotes, cell division occurs in two main stages, mitosis and cytokinesis. Mitosis is the division of the nucleus. Cytokinesis is the division of the cytoplasm. The cell cycle is a series of events cells go through as they grow and divide. During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells.

3.4.1 Comparison of the three types of cell division

Let us now consider the similarities and differences between the tree cell divisions of binary fission, mitosis, or meiosis.
Discuss Meiosis also.

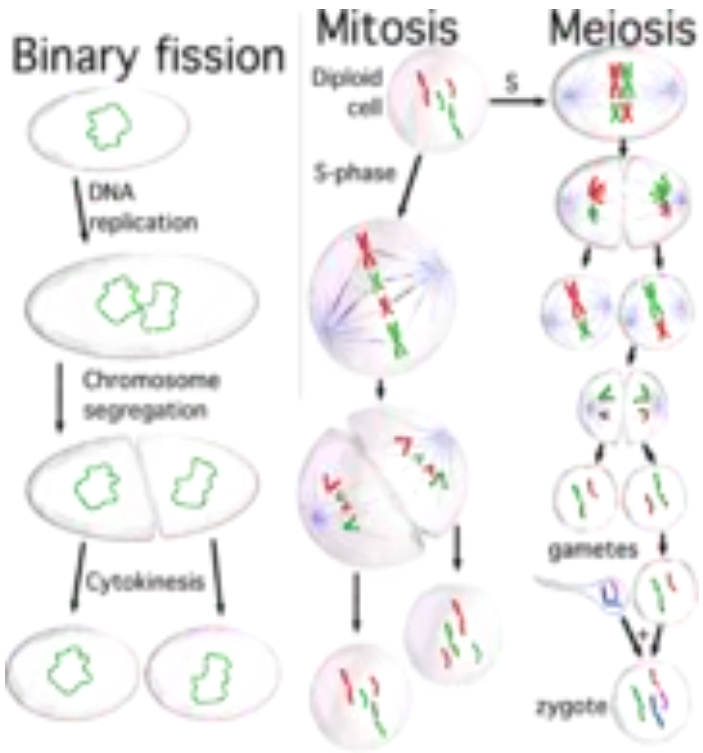


Fig. 16 Cell growth
Source: Copyright © 2009 Answers Corporation

The DNA content of a cell is duplicated at the start of the cell division process. Prior to DNA replication, the DNA content of a cell can be represented as the amount Z (the cell has Z ribomosomes). After the DNA replication process, the amount of DNA in the cell is 2Z (multiplication: 2 x Z = 2Z). During binary fission and mitosis the duplicated DNA content of the reproducing parental cell is separated into two equal halves that are destined to end up in the two daughter cells. The final part of the cell duplication process is cell division, when daughter cells physically split from a parental cell.

During meiosis, there are two cell division steps that together produce the four daughter cells. Meiosis is a cell division longer than either mitosis or binary fission. It is a reduction cell division in reproductive cells.

After the completion of binary fission or cell reproduction involving mitosis, each daughter cell has the same amount of DNA (Z) as what the parental cell had before it replicated its DNA. These two types of cell division produce two daughter cells that have the same number of chromosomes as the parental cell. After meiotic cell division four daughter cells are produced that have half the number of chromosomes that the parent cell originally had. This is often symbolized as N the haploid amount of DNA. Meiosis occurs in diploid organisms to produce haploid gametes. In a diploid

organism such as the human organism, most cells of the body have the diploid amount of DNA, 2N. Using this notation for counting chromosomes we say that human somatic cells have 46 chromosomes (2N = 46) while human sperm and egg each has 23 chromosomes (N = 23). Humans have 23 distinct types of chromosomes, the 22 autosomes and the special category of sex chromosomes.

There are two distinct sex chromosomes, the X chromosome and the Y chromosome. A diploid human cell of an individual human being has 46 chromosomes inherited from that person's father and the mother. That is, your body has two copies of human chromosome number 2, one from each of your parents.

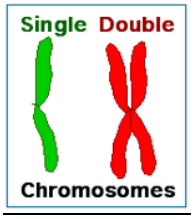


Fig. 17 Chromosomes
(Source: Copyright © 2009 Answers Corporation)

During mitosis, immediately after DNA replication a human cell will have 46 "double chromosomes". In each double chromosome there are two copies of that chromosome's DNA molecule. During mitosis the double chromosomes are split to produce 92 "single chromosomes", half of which go into each daughter cell. During meiosis, the 46 chromosomes are reduced to half, 23 there are two chromosome separation steps which assure that each of the four daughter cells gets one copy of each of the 23 chromosomes.

3.4.2 Sexual reproduction

In eukaryotes, e.g. in humans, meiosis occurs in sex organs (testes and ovaries) to produce gametes (sperm and egg cell). During sexual reproduction to produce a new human being (foetus), meiosis brings about genetic recombination events between sets of chromosomes. During this period, new combinations of genes in the chromosomes occur. In organisms with more than one set of chromosomes (humans) random mating produces homozygotes and heterozygotes.

3.4.3 Regulating the Cell Cycle

Normal cells divide and reproduce when the need arises. In a multicellular organism, cell growth and cell division are carefully controlled by certain factors. For instance, when an injury such as a cut in the skin occurs, cells at the edge of the cut divide rapidly. When the healing process is nearly complete, the rate of cell division slows down and then returns to normal.

3.4.4 Why do cells divide?

Cells in a multicellular organism have different sizes, rates of growth and timing of cell division. Cells in a multicellular organisms divide to replace lost or damage cells and allow the organism to grow. Unicellular organisms divide to reproduce. Cells must divide for two main reasons:

- Not enough DNA to provide the information a cell needs to survive
- The surface area of a cell does not increase as fast as the volume of the cell.

3.5 Cellular Growth Disorders

A series of growth disorders can occur at the cellular level. A normal cell can become a cancer cell. Cancer is a disorder in which some of the body's cells lose the ability to control growth. Cancer cells do not respond to the signals that control the growth of normal cells. As a result, cancer cells divide uncontrollably. They form masses of cells called tumors, which can damage surrounding tissues. Cancer cells do not stop growing when they touch other cells. Instead, they continue to grow and divide until their supply of nutrients is used up. Cancer cells may break loose from tumors and spread throughout the body. Cancer cells can invade other cells (invasion) and spread to other locations of the body, a process that is called metastasis.

Activity

1. In a cell the continuous process of mitosis cell division growth and interphase is known as what?
2. Is growth accomplished by both cell divisions and cell enlargement?
3. How do cell growth and cell division relate?
4. What is the difference between cell differentiation and cell growth?
5. What are the causes of cell growth?
6. What is necessary for cell growth and energy?
7. It is possible to have growth without cell division?
8. What is the growth period of the cell cycle known as?
9. How does cell division effect growth?
10. Does cell growth occur in mitosis?
11. How do cancer cells grow in the body?
12. Why are cancerous cell different from normal cells?
13. What are the major events during G2 phase?
14. Which cell organelles are involved in cell division?
15. What factors limit cell growth?

4.0 CONCLUSION

When cells grow and differentiate, they reach maturity and under certain conditions they undergo cell division to produce normal cells but sometimes cell disorders may occur.

5.0 SUMMARY

In this unit we have learnt that:

- Cell number is proportional to the rate of cell proliferation and the rate of cell death.
- The process of cell birth and cell death is termed cell turnover.
- Cell turnover is very slow, and cell proliferation occurs primarily after injury.
- Cell division is more complex in eukaryotes than in other organisms.
- Binary fission, mitosis, and meiosis are types of cell division.
- There are reasons why cells divide
- Cell disorders during cell division may occur.

6.0 TUTOR MARKED ASSIGNMENT

1. List the differences between cellular growth and cellular differentiation
2. Distinguish between normal cell growth and cell growth disorder
3. Describe cell number, cell population and cell size

7.0 FURTHER READING AND OTHER RESOURCES

Cooper, G. (2000). "The Events of M Phase". The Cell: A Molecular Approach. Sinaeur Associates, Inc.

Dornelas, M.C. (2003). Signal transduction, cell division, differentiation and development: towards unifying mechanisms for pattern formation in plants. Braz. J. Plant Physiol. 15:1-8.

Freeman, S (2002). "Cell Division".BiologicalScience.Upper Saddle River, NJ: Prentice Hall. pp.155–174. ISBN 0-13-081923-9.

Morgan, D.O. (2007). "The Cell Cycle: Principles of Control" London: New Science Press.

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UNIT 5: THE CELL CYCLE AND MITOSIS

Contents

1.0 INTRODUCTION

In module 2 unit 3, mitosis was described in details and related to cell cycle. For emphasis, in this unit the processes leading to mitosis where duplicated genetic materials (chromosomes) creating two identical daughter cells will be discussed. Therefore unit 3 and unit 5 are almost the same. This exercise is designed to introduce you to the events that occur in the cell cycle

2.0 A: OBJECTIVES

By the end of this unit, you should be able to:

- Discuss mitosis
- Diagrammatically illustrate mitosis

2.0 B: HOW TO STUDY THIS UNIT

1. You are expected to read carefully through this unit twice before attempting to answer the activity questions. Do not look at the solution or guides provided at the end of the unit until you are satisfied that you have done your best to get all the answers.
2. Share your difficulties in understanding the unit with your mates, facilitators and by consulting other relevant materials or internet.
3. Ensure that you only check correct answers to the activities as a way of

confirming what you have done.

4. Note that if you follow these instructions strictly, you will feel fulfilled at the end that you have achieved your aim and could stimulate you to do more.

3.0 MAIN CONTENTS

3.1 What is mitosis?

Mitosis is a nuclear division with cytokinesis, which produces two identical daughter cells during prophase, prometaphase, metaphase, anaphase, and telophase from a single parent cell

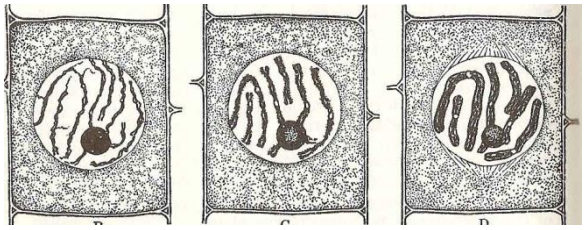
3.1.1 Interphase

Interphase is often included in discussions of mitosis, but interphase is technically not part of mitosis, but rather encompasses stages G1, S, and G2 of the cell cycle.

The cell is engaged in metabolic activity and being prepared for mitosis. Chromosomes are not clearly discerned in the nucleus, although a dark spot called the nucleolus may be visible. The cell may contain a pair of centrioles (or microtubule organizing centers in plants) both of which are organizational sites for microtubules. Each chromosome is duplicated as two chromatins (remember Unit 3?)

3.1.2 Prophase

Each chromatin in the nucleus begins to condense and becomes visible under the light microscope as chromosomes. The nucleolus disappears. Centrioles begin to move to opposite ends of the cell and fibers extend from the centromeres. Some fibers cross the cell to form the mitotic spindle (Fig. 18).



(a) (b) (c)

Fig. 18a-c Prophase

(Source: Dutta A.C. 1981 Botany 5th edition)

3.1.3 Prometaphase

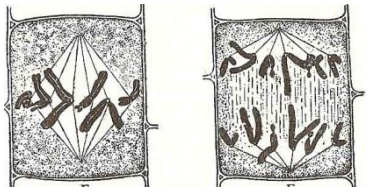
The nuclear membrane dissolves, marking the beginning of prometaphase. Proteins attach to the centromeres creating the kinetochores. Microtubules attach at the kinetochores and the chromosomes begin moving.

3.1.4. Metaphase

Spindle fibers align the chromosomes along the middle of the cell nucleus (Fig. 18a). This arrangement in a line is referred to as the metaphase plate. This organization helps to ensure that in the next phase, when the paired chromosomes are separated, each new nucleus will receive one copy of each chromosome.

3.1.5 Anaphase

The paired chromosomes separate at the kinetochores and move to opposite sides of the cell (Fig. 19b) separation results from a combination of kinetochore movement along the spindle microtubules and through the physical interaction of polar microtubules.



(a) (b)

Fig. 19 a-b Metaphase (a) and Anaphase (b)
(Source: Dutta A.C. 1981 Botany 5th edition)

3.1.6 Telophase

Chromatids arrive at opposite poles of cell, (Fig. 20a) and new nuclear membranes form around the daughter nuclei (Fig. 19b). The chromosomes disperse and are no longer visible under the light microscope. The spindle fibers disperse, and cytokinesis or the partitioning of the cell may also begin during this stage (Fig. 30c).

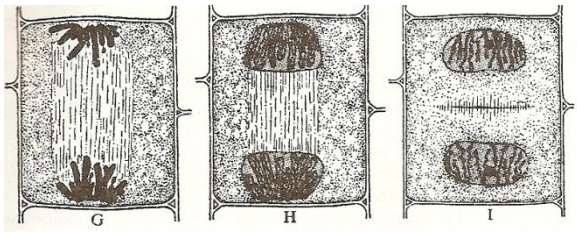


Fig. 20a Telophase
Source: Dutta A.C. 1981 Botany 5th edition

3.1.7 Cytokinesis

In animal cells, cytokinesis results when a fiber ring composed of a protein called actin around the center of the cell contracts pinching the cell into two daughter cells, each with one nucleus. In plant cells, the rigid wall requires that a cell plate be synthesized between the two daughter cells.

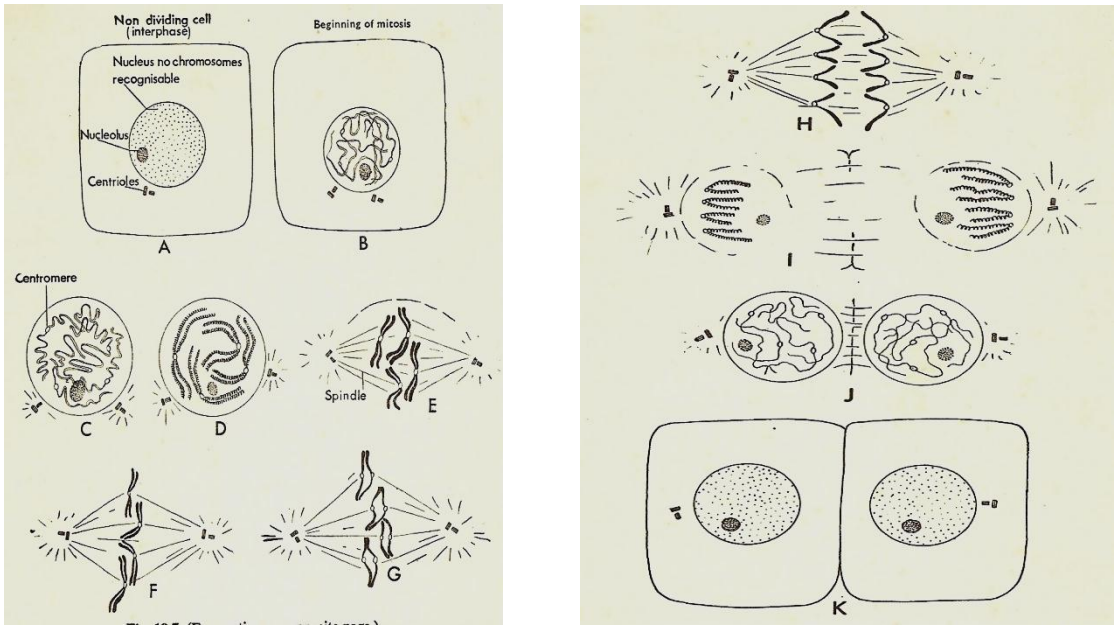


Fig. 21A-K Diagrams illustrating mitotic cell division: A Interphase; B, C, D and E Prophase; F Metaphase. G, H and I Anaphase; J and K Telophase.
(Source: Chapman, G. and Barker, W.B. Zoology Longmans 1968)

Activity

Problem 1: Cell Cycle Stages

The stage of the cell cycle where each chromosome is composed of two chromatids in preparation for mitosis.

A. G1
B. S
C. M
D. G2

Problem 2: Cell Cycle Sequence

Which sequence of the cell cycle is common to eukaryotes?

A. G1 to G2 to S to M to cytokinesis
B. G1 to M to G2 to S to cytokinesis
C. G1 to S to M to G2 to cytokinesis
D. G1 to S to G2 to M to cytokinesis

Problem 3: Cell Cycle Stages

The stage of the cell cycle where the cell is preparing to begin DNA replication is called:

A. G1
B. G2
C. S

D. M

Problem 4: Animals vs. plants
Which of the following phase or processes of cell division is very different plant cells?
A. prophase
B. metaphase
C. anaphase
D. cytokinesis

Problem 5: Chromosomes
Prior to cell division, each chromosome replicates or duplicates its genetic material. The products are connected by a centromere and are called:
A. sister chromosomes
B. homologous chromosomes
C. sex chromosomes
D. sister chromatids

Problem 6: Mitosis Stages
The first stage of mitosis when chromosomes start becoming visible in the microscope is called:
A. anaphase
B. prophase
C. telophase
D. metaphase

Problem 7: Mitosis
Which of the following statements is NOT true of mitosis?
A. A single nucleus gives rise to two identical daughter nuclei.
B. The daughter nuclei are genetically identical to the parent nucleus.
C. The centromeres divide at the onset of anaphase.
D. Homologous chromosomes synapse in prophase.

Problem 8: Cytokinesis
Cytokinesis in a plant cell is characterized by:
A. the equal division of homologous chromosomes.
B. a pinching off of the cell membrane to divide the cell.
C. the formation of a cell plate in the cytoplasm.
D. the movement of the chromosomes from the metaphase plate.

4.0 CONCLUSION

Mitosis produces two identical daughter cells from a single parent cell.

5.0 SUMMARY

In this unit we have learnt that:

- The various phases of mitosis ultimately give rise to two identical daughter cells.

6.0 TUTOR MARKED ASSIGNMENT

How many phases make up mitosis? Identify the major events of each phase, using diagram to illustrate.

7.0 FURTHER READING AND OTHER RESOURCES

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K. & Walter, P. (2002)."Mitosis".Molecular Biology of the Cell.Garland Science.

De Souza, C.P., Osmani, S.A. (2007). "Mitosis, not just open or closed". *Eukaryotic Cell* 6 (9): 1521–1527.

Gubb, D. (1998) Cellular polarity, mitotic synchrony and axes of symmetry during growth. Where does the information come from? *Int. J. Dev. Biol*. 42:369-377.

Lloyd, C., Chan, J. (2006). "Not so divided: the common basis of plant and animal cell division". Nature reviews. *Molecular Cell Biology* 7 (2): 147–152.