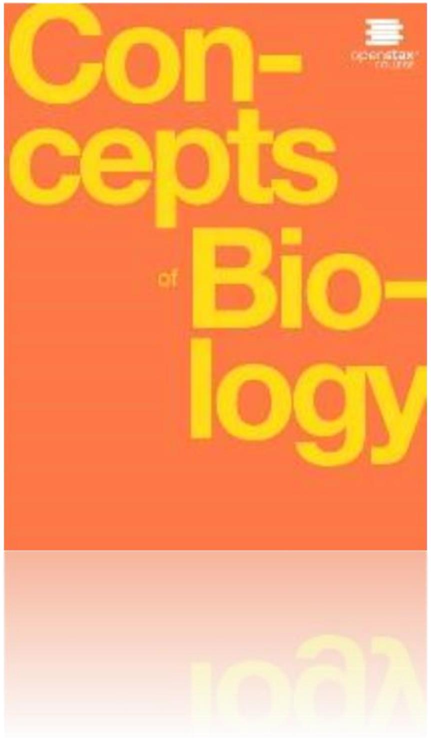
CONCEPTS OF BIOLOGY

Chapter 6 REPRODUCTION AT THE CELLULAR LEVEL

PowerPoint Image Slideshow



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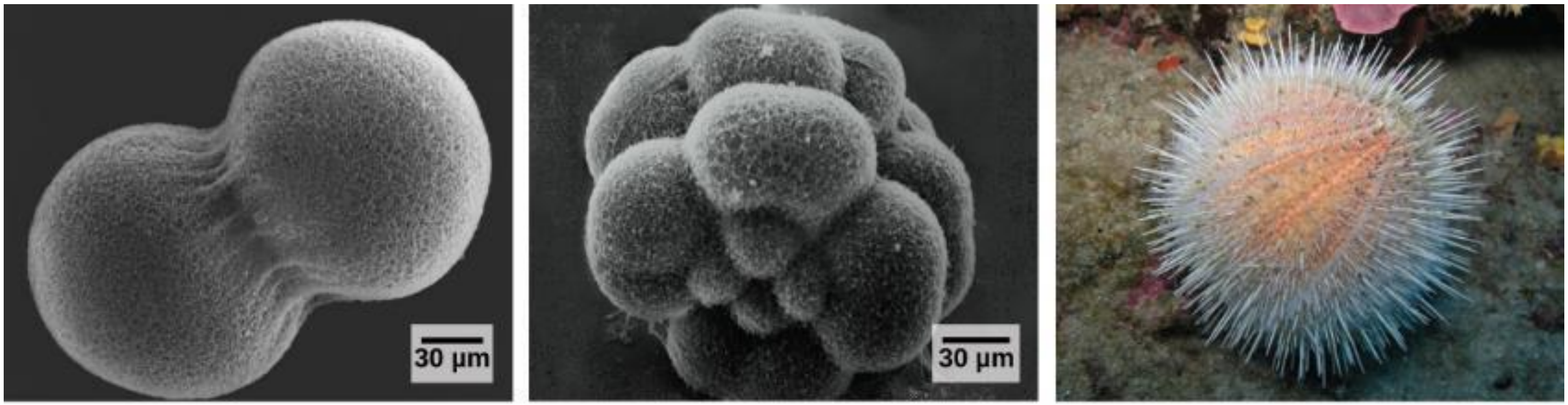
Introduction

- Sexually reproducing organisms (including humans) begin life as a fertilized egg, or **zygote**
- This zygote becomes the ancestor of all the trillions of cells that make up the entire multicellular organism like a human
- Even after the individual is fully grown, cell reproduction is still necessary to repair and regenerate tissues
- Single-celled organisms use cell division as their method of reproduction

FIGURE 6.1



(a) (b) (c)

A sea urchin begins life as a single cell that (a) divides to form two cells, visible by scanning electron microscopy. After four rounds of cell division, (b) there are 16 cells, as seen in this SEM image. After many rounds of cell division, the individual develops into a complex, multicellular organism, as seen in this (c) mature sea urchin. (credit a: modification of work by Evelyn Spiegel, Louisa Howard; credit b: modification of work by Evelyn Spiegel, Louisa Howard; credit c: modification of work by Marco Busdraghi; scale-bar data from Matt Russell)

6.1 THE GENOME

- **Cell cycle** - an orderly sequence of event in the life of a cell from the division of a single parent cell to produce two new daughter cells
- The mechanisms involved in the cell cycle are highly conserved across eukaryotes, organisms as diverse as protists, plants, and animals employ similar steps

Genomic DNA (1 of 4)

- A cell's complete complement of DNA is called it's **genome**
- In prokaryotes, the genome is composed of a single, double-stranded DNA molecule in the form of a loop or a circle. This region is called the **nucleoid**
- In eukaryotes, the genome is comprised of several double-stranded, linear DNA molecules bound with proteins to form complexes called **chromosomes**

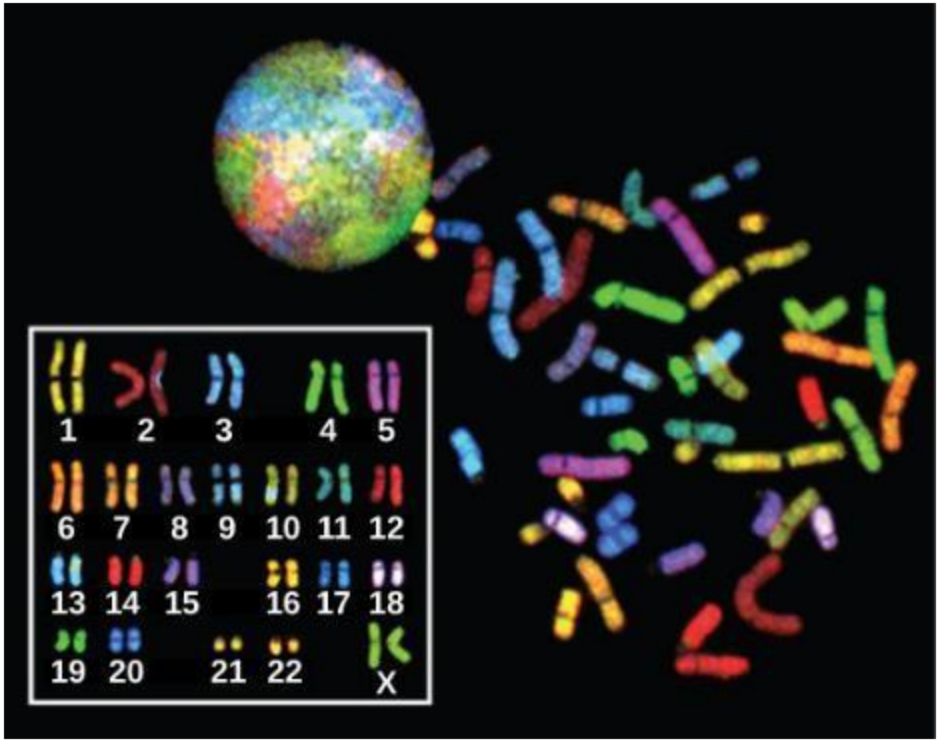
Genomic DNA (2 of 4)

- Each species of eukaryote has a characteristic number of chromosome in the nuclei of its cells (human body cells have 46 chromosomes)

Genomic DNA (3 of 4)

- **Somatic cells** (body cells) contain two matched sets of chromosomes, these cells are described as **diploid (2n)**
- **Gametes** (sex cells, egg and sperm for humans) contain only one set of chromosomes, these cells are described as **haploid (n)**

FIGURE 6.2



There are 23 pairs of homologous chromosomes in a female human somatic cell. These chromosomes are viewed within the nucleus (top), removed from a cell in mitosis (right), and arranged according to length (left) in an arrangement called a karyotype. In this image, the chromosomes were exposed to fluorescent stains to distinguish them. (credit: “718 Bot”/Wikimedia Commons, National Human Genome Research)

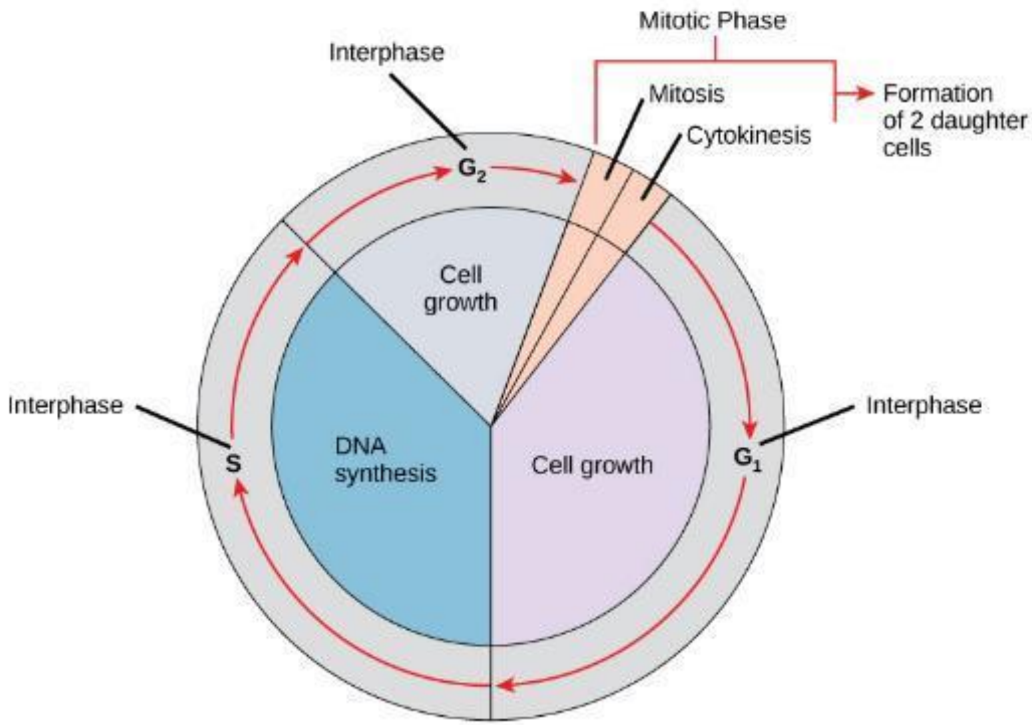
Genomic DNA (4 of 4)

- **Homologous chromosomes** (sometimes called **homologues**) are the matched pairs of chromosomes in a diploid organism
- Homologous chromosomes are the same length and have specific nucleotide segments called **genes** in exactly the same location, or **locus**
- Genes (the functional units of chromosomes) determine specific characteristics by coding for specific proteins
- Each homologue originates from a different parent, therefore the copies of the genes themselves may not be identical

6.2 THE CELL CYCLE

- The **cell cycle** is an ordered series of events involving cell growth and cell division that produces two new daughter cells
- Has two major phases:
  - **Interphase** – the cell grows and DNA is replicated
  - **Mitosis** – the replicated DNA and cytoplasmic contents are separated and the cell divides

FIGURE 6.3



A cell moves through a series of phases in an orderly manner. During interphase, G_1 involves cell growth and protein synthesis, the S phase involves DNA replication and the replication of the centrosome, and G_2 involves further growth and protein synthesis. The mitotic phase follows interphase. Mitosis is nuclear division during which duplicated chromosomes are segregated and distributed into daughter nuclei. Usually the cell will divide after mitosis in a process called cytokinesis in which the cytoplasm is divided and two daughter cells are formed.

Interphase (1 of 2)

- During interphase, the cell undergoes normal processes while also preparing for cell division
- Interphase is subdivided into 3 stages:
  - G_1, S, and G_2

Interphase (1 of 2)

- **G_1 (First Gap) phase** – the cell is very active at the biochemical level. It is accumulating the building blocks of chromosomal DNA and proteins, as well as accumulating an energy reserve
- **S (Synthesis) phase** – DNA replication results in the formation of two identical copies of each chromosome that are attached at the centromere region (sister chromatids)
- **G_2 (Second Gap) phase** – replenishes energy stores and synthesizes the proteins necessary for chromosome manipulation. Organelles are duplicated, cytoskeleton is dismantled and additional growth occurs

The Mitotic Phase

- **Mitotic phase** - is a multistep process during which the duplicated chromosomes are divided into two identical daughter cells
- Consists of mitosis (divided into 5 stages) and cytokinesis

Mitosis (1 of 6)

- Mitosis - a series of phases that result n the division of the cell nucleus
- Includes: prophase, prometaphase, metaphase, anaphase and telophase

Mitosis (2 of 6)

- **Prophase** – the “first phase”
  - Nuclear envelope breaks down
  - Golgi apparatus, endoplasmic reticulum and nucleolus fragment and disappear
  - Centrosomes moves to opposite poles
  - Mitotic spindle is forming
  - Sister chromatids coil more tightly and become visible under a light microscope

Mitosis (3 of 6)

- **Prometaphase** –
  - Continuation of the events of prophase
  - Sister chromatids are attached to the spindle microtubules at the centromere via a protein complex called the **kinetochore**

Mitosis (4 of 6)

- **Metaphase** –
  - All chromosomes are aligned in a plane called the **metaphase plate** (also called equatorial plane), midway between the two poles of the cell

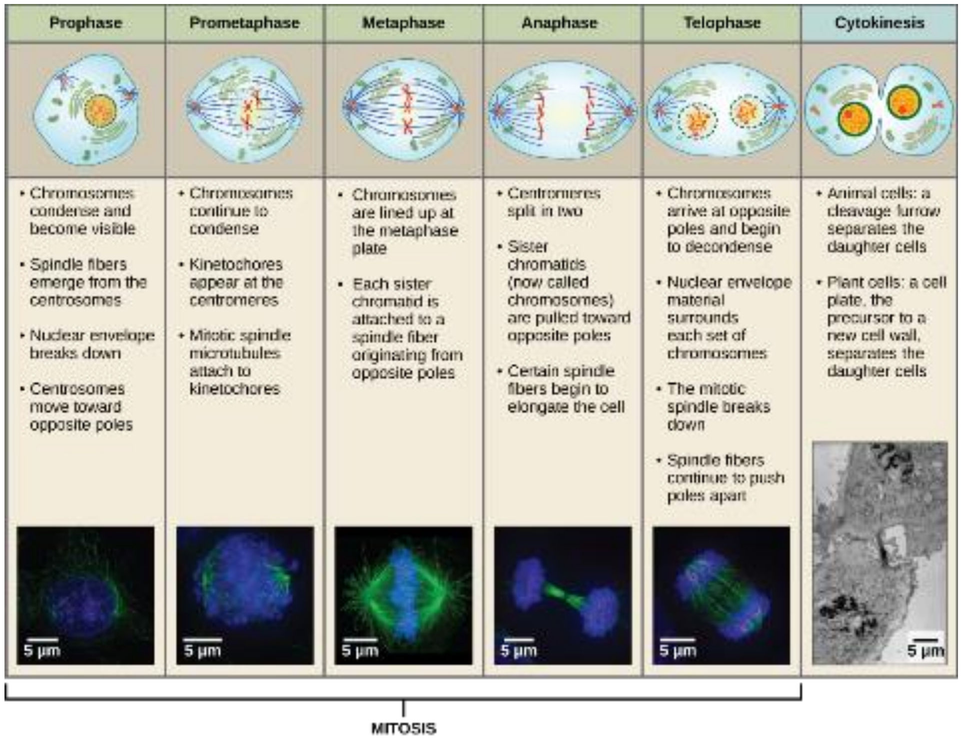
Mitosis (5 of 6)

- **Anaphase** –
  - Sister chromatids at the equatorial plane are split apart at the centromere
  - The separated chromatids are pulled toward the opposite poles

Mitosis (6 of 6)

- **Telophase** –
  - All the events of prophase are reversed
  - Nuclear envelopes develop around the clusters of chromosomes
  - Nucleolus and other organelles reappear
  - Mitotic spindle fragments
  - Chromosomes begin to decondense (unravel), cytoskeleton reassembles

FIGURE 6.4

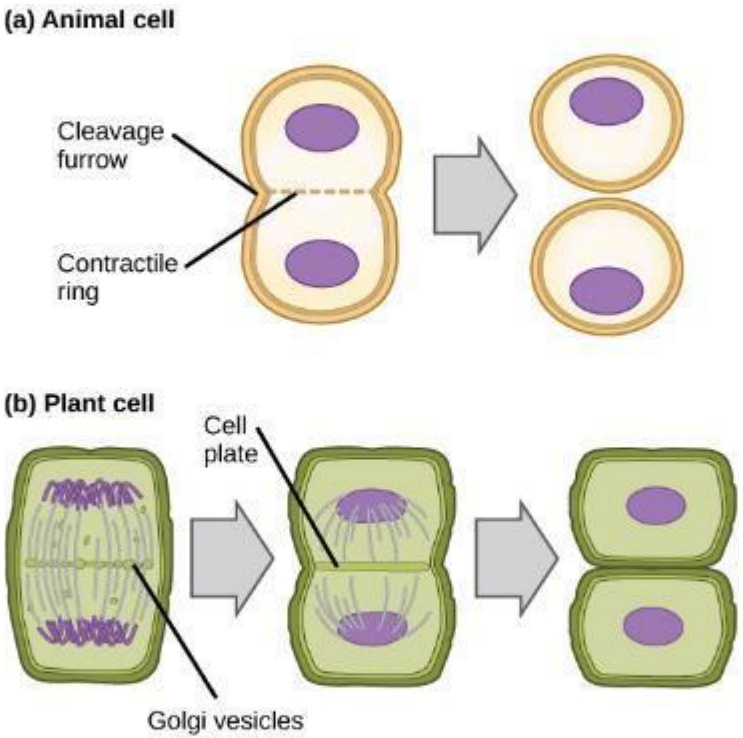


Animal cell mitosis is divided into five stages—prophase, prometaphase, metaphase, anaphase, and telophase—visualized here by light microscopy with fluorescence. Mitosis is usually accompanied by cytokinesis, shown here by a transmission electron microscope. (credit “diagrams”: modification of work by Mariana Ruiz Villareal; credit “mitosis micrographs”: modification of work by Roy van Heesbeen; credit “cytokinesis micrograph”: modification of work by the Wadsworth Center, NY State Department of Health; donated to the Wikimedia foundation; scale-bar data from Matt Russell)

Cytokinesis

- The physical separation of the cytoplasmic components into two daughter cells
- Occurs differently for animal and plant cells
  - **Animal cells** – a contractile ring of actin filaments form a **cleavage furrow** that deepens to cleave the cell into two
  - **Plant cells** – vesicles containing structural proteins form at the metaphase plate, fuse together and form a **cell plate**. The cell plate extends toward the cell wall and enzymes convert the cell plate into a new cell wall

FIGURE 6.5

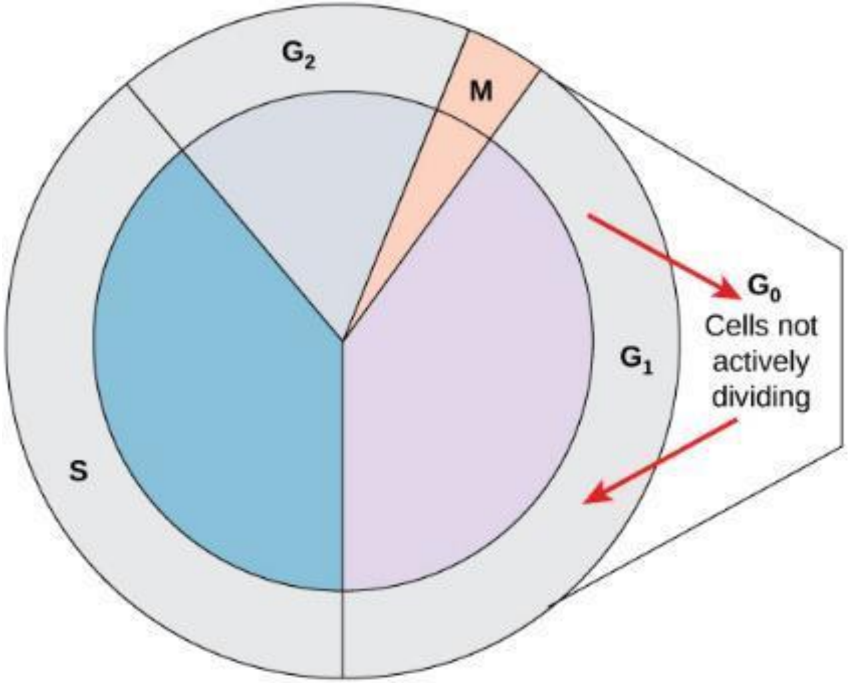


In part (a), a cleavage furrow forms at the former metaphase plate in the animal cell. The plasma membrane is drawn in by a ring of actin fibers contracting just inside the membrane. The cleavage furrow deepens until the cells are pinched in two. In part (b), Golgi vesicles coalesce at the former metaphase plate in a plant cell. The vesicles fuse and form the cell plate. The cell plate grows from the center toward the cell walls. New cell walls are made from the vesicle contents.

G_0 Phase

- Some cells enter into the G_0 phase and are not actively dividing
- Some cells enter this phase temporarily until an external signal triggers the onset of G_1, while other cells remain in G_0 and never divide (such as cardiac muscle or nerve cells)

FIGURE 6.6



Cells that are not actively preparing to divide enter an alternate phase called G_0. In some cases, this is a temporary condition until triggered to enter G_1. In other cases, the cell will remain in G_0 permanently.

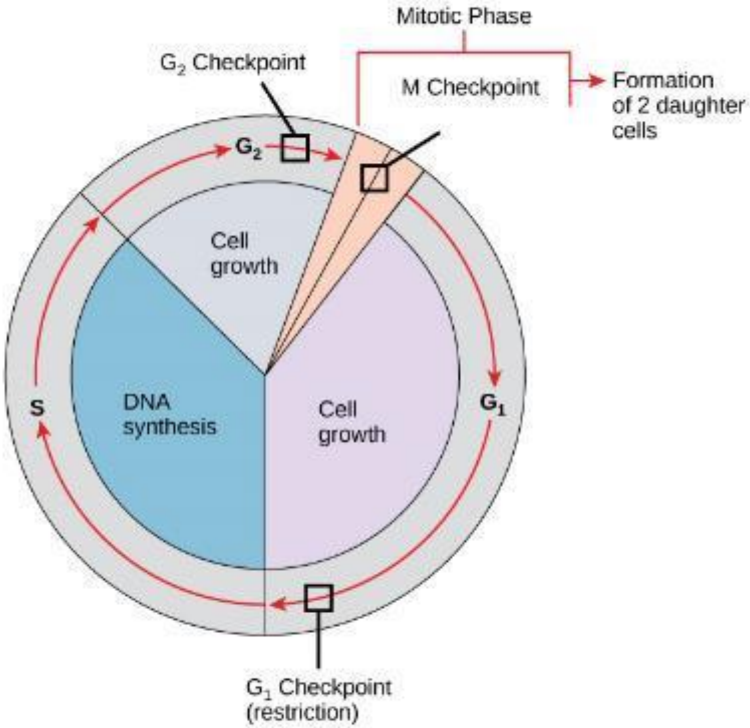
Control of the Cell Cycle

- The length of the cell cycle varies greatly, depending on the cell
- For example, early embryonic cells divide every few hours; skin cells divide on average every 2-5 days; and nerve cells and muscles cells never divide
- The timing of the events of the cell cycle is controlled by mechanisms that are both internal and external to the cell

Regulation at Internal Checkpoints

- It is essential that daughter cells be exact duplicates of the parent cell
- To prevent a compromised cell from continuing to divide, there are internal control mechanisms that operate at three main **cell cycle checkpoints**, at which the cell cycle can be stopped until conditions are favorable
- These checkpoints occur near the end of G_1, at the G_2-M transition, and during metaphase

FIGURE 6.7



The cell cycle is controlled at three checkpoints. Integrity of the DNA is assessed at the G_1 checkpoint. Proper chromosome duplication is assessed at the G_2 checkpoint. Attachment of each kinetochore to a spindle fiber is assessed at the M checkpoint.

Regulation at Internal Checkpoints (1 of 3)

- **The G_1 checkpoint** – (also called the restriction point), determines whether all conditions are favorable for cell division to proceed
- The point at which the cell irreversibly commits to cell division
  - Checks for adequate reserves, cell size, DNA damage
  - A cell that does not meet all the requirements will not be released into the S phase

Regulation at Internal Checkpoints (2 of 3)

- **The G_2 checkpoint** – bars the entry to the mitotic phase if certain conditions aren’t met
  - Once again assesses cell size and protein reserves
  - Most importantly, ensures that all of the chromosomes have been replicated and that the replicated DNA is not damaged

Regulation at Internal Checkpoints (3 of 3)

- **The M checkpoint** – (also called the spindle checkpoints) occurs near the end of the metaphase stage of mitosis
  - Determines if all sister chromatids are correctly attached to the spindle microtubules

6.3 CANCER AND THE CELL CYCLE

- **Cancer** is a collective name for many diseases caused by a common mechanism: **uncontrolled cell division**
- All cancers begin when a gene mutation gives rise to a faulty protein that participates in the process of cell reproduction

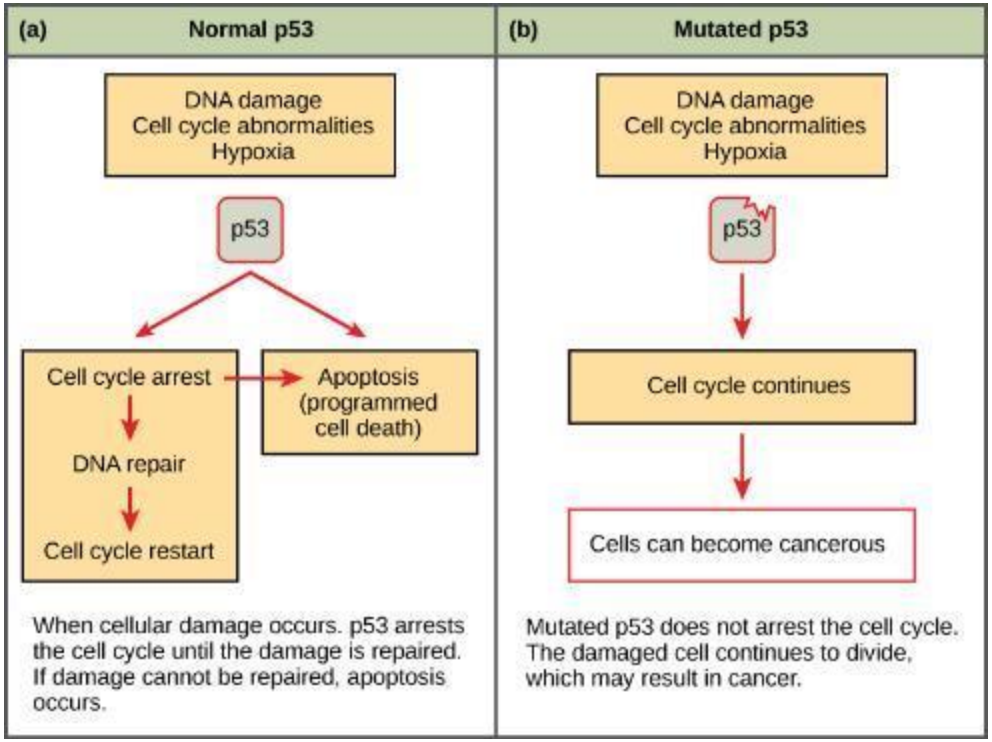
Proto-oncogenes

- **Proto-oncogenes** are genes that code for the positive cell-cycle regulators
- Proto-oncogenes are normal genes, that when mutated become **oncogenes** – genes that cause a cell to become cancerous
- Example: Cdk is a protein involved in cell-cycle regulation, it is considered a proto-oncogene. If this gene become mutated and allows the cell-cycle checkpoints to be overrode (increasing the rate of the cell cycle), it is then called an oncogene

Tumor Suppressor Genes

- Genes that code for the negative regulator proteins, that when activated, prevent the cell from undergoing uncontrolled division are called **tumor suppressor genes**
- **p53** is a gene that codes for a protein that plays multiple roles in the G_1 checkpoint
- This protein activates genes involved in DNA repair, or cell death when DNA can not be repaired
- When the p53 gene is mutated, it allows mutated daughter cells to divide and accumulates new mutations

FIGURE 6.8



(a) The role of p53 is to monitor DNA. If damage is detected, p53 triggers repair mechanisms. If repairs are unsuccessful, p53 signals apoptosis.

(b) A cell with an abnormal p53 protein cannot repair damaged DNA and cannot signal apoptosis. Cells with abnormal p53 can become cancerous. (credit: modification of work by Thierry Soussi)

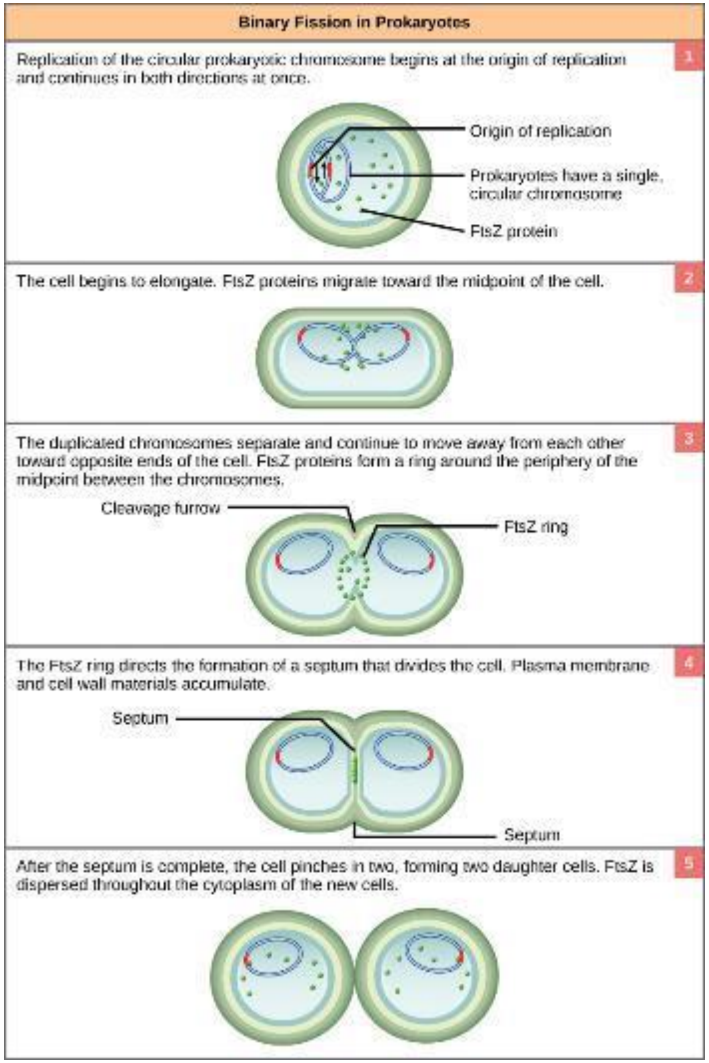
6.4 PROKARYOTIC CELL DIVISION

- Prokaryotes such as bacteria propagate by binary fission
- For unicellular organisms, cell division is the only method to produce new individuals
- The outcome of this cell reproduction is a pair of daughter cells that are genetically identical to the parent cell
- Because prokaryotes do not have a nucleus, mitosis is unnecessary, these cells must replicate genomic DNA and allocate it, along with the cytoplasmic content to the two daughter cells. This type of cell division is called **binary fission**

Binary Fission

- Binary fission is less complicated and much quicker than cell division is eukaryotes; therefore populations of bacteria can grow very rapidly
- DNA replication begins at the starting point called the **origin**, and bidirectionally moves away from the origin
- After the chromosomes have cleared the midpoint of the elongated cell, cytoplasmic separation begins
- A **septum** is formed between the nucleoids from the periphery toward the center of the cell
- When the new cell walls are in place, the daughter cells separate

FIGURE 6.9



The binary fission of a bacterium is outlined in five steps. (credit: modification of work by "Mcstrother"/Wikimedia Commons)