Cell Division (Outline)

1. Overview of purpose and roles. Comparison of prokaryotic and eukaryotic chromosomes and relation between organelles and cell division.

2. Eukaryotic cell reproduction: asexual & sexual (sameness and variety) .
   Alternation of human cell generations (haploid: gametes/diploid: somatic cells & germ line cells)

3. Broad comparison of mitosis and meiosis: mother cells, # of cell division, daughter cells sameness and variability.

4. Eukaryotic cell cycle and physical status of DNA at different phases.

5. Mitosis and cytokinesis: division of genetic material and cytoplasm
   Mitosis and its continuum of sub-phases
   Cytokinesis in animal and plant cells


7. Cell Cycle control: Check points, purpose, mechanism, and response to external and internal controls.

8. Role of programmed cell death for normal growth and development
Somatic cells- Body cells (diploid)
Gametes - sperm or egg (haploid)
Key Roles of Cell Division

- Reproduction
- Growth
- Repair

Purpose: distribution of genetic material to daughter cells

Genomes: haploid and diploid

Sea Urchin cell division

http://www.exploratorium.edu/imaging_station/
Major Events in the History of Earth

- Origin of solar system and Earth
- Archaean eon
- Proterozoic eon
- Paleozoic
- Mesozoic
- Cenozoic
- Humans

Key Events:
1. Billions of years ago
2. 2
3. 3
4. 4

- Land plants
- Animals
- Multicellular eukaryotes
- Single-celled eukaryotes
- Prokaryotes

- Atmospheric oxygen
- Diploid nucleus
- Haploid nuclei
- Haploid
Comparison

Prokaryotic organisms
- Haploid cells
- Single circular chromosome

Eukaryotic organisms
- Haploid gametes
- Multiple linear chromosomes (# varies between species)
Three types of cell division in living cells

Prokaryotic cells: Binary fission
Eukaryotic Cells: Mitosis and Meiosis
Prokaryotic cell division

- Binary Fission
- circular chromosome replicates

- two daughter chromosomes actively move apart
The Mitotic Spindle

An apparatus of microtubules that controls chromosome movement during mitosis

Arises from the centrosome
Eukaryotic Cell division

1. **Asexual** reproduction (Identical cells)
   - Unicellular/ *Amoeba*
   - Some multi-cellular eukaryotes *plants* and some *animals* like hydra (diploid), by budding cells
Eukaryotic Cell division

2. Sexual reproduction (non-identical cells-variability)

Most multi-cellular organisms have both Asexual and sexual reproduction
Cell Reproduction in Humans

**Somatic** cells (sameness)

**Germ** cells of the gonads (variability)

**Mitosis** produces 2 genetically identical cells

**Meiosis** produces 4 genetically non-identical cells each with \( \frac{1}{2} \) the number of chromosomes
Cell Division

- One mother cell divides into two cells following an ordered sequence of events (Cell Cycle)

- Summary of sequence of events of dividing cells
  - Replicate the genetic material
  - Manufacture additional cellular content
  - Divide the nucleus
  - Separate the cytoplasm
Cell Cycle

From mother cell to two daughter cells

Mitosis or Meiosis division of the nucleus

Cytokinesis division of the cytoplasm

www.cellsalive.com
State of DNA inside a living cell

In a non dividing and in a dividing cell

• Packaging of long strands of DNA into small nucleus (chromatin: non-dividing).

• Condensation of chromatin into short condensed chromosomes in a dividing cell.

How DNA is Packaged

https://www.youtube.com/watch?v=9kQpYdCnU14
Chromatin

- Chromosome
- Nucleosome
- DNA double helix
- Coils
- Histones

INTERPHASE

- G₁ (DNA synthesis)
- S
- G₂

MITOTIC PHASE (M)

Cytokinesis

1. DNA molecule
2. Supercoils
3. Coils
4. Histones
5. Chromosome
State of DNA inside a living cell

In a non-dividing cell- DNA (2-3 m) is coiled as Chromatin (DNA + proteins/histones)

In a dividing cell- chromatin condenses to form chromosomes (Chromatin + scaffold proteins)
Replication of Chromosomes

Chromosomes are replicated during S phase prior to mitosis.

The result is two sister chromatids held together at the centromere.
Phases of Interphase

Interphase

– the G₁ phase ("first gap") - growth (protein synthesis and organelles present)
– the S phase ("synthesis") - DNA replication
– the G₂ phase ("second gap") - completes preparations for nuclear division

Follow cellular DNA content in time
Mitosis

Mitosis is a continuum of changes broken into five sub-phases:

- Prophase
- Prometaphase
- Metaphase
- Anaphase
- Telophase
- Centrosome- a pair of centrioles, microtubule organizing center (MOC).
- Spindle fibers- mirotubules (tubulin)
- Nuclear membrane
- Nucleolus
- Loose chromatin
- Condensed chromosome –two sister chromatids held by centromere
The Mitotic Spindle

Types of microtubules

Kinetochore microtubules

Attach to the kinetochores of chromosomes and move the chromosomes to the metaphase plate

Non-kinetochore microtubules

From opposite poles overlap and push against each other, elongating the cell
Cytokinesis in animal and plant cells

(a) Cleavage of an animal cell

(b) Cell plate formation in a plant cell
<table>
<thead>
<tr>
<th>Animal cells</th>
<th>Plant Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleavage furrow</td>
<td>Cell plate</td>
</tr>
<tr>
<td>Microfilament (actin) and myosin contracting ring</td>
<td>Golgi-derived vesicles</td>
</tr>
</tbody>
</table>
Meiosis

• Two consecutive cell divisions, meiosis I and meiosis II

• Important to remember:
  – Prophase I: tetrad formation between homologous chromosomes, synapsis, cross-over (recombination)
  – Arrangement of chromosomes at metaphase I
  – Separation of recombinant homologous chromosomes during Anaphase I.
  – Arrangement of chromosomes at metaphase I.
Meiosis

- Results in four daughter cells
- Each final daughter cell has only half as many chromosomes as the parent cell
**Interphase 1 of Meiosis**

1. Homologous pair of chromosomes in diploid parent cell
2. Chromosomes replicate
3. Homologous pair of replicated chromosomes
4. Diploid cell with replicated chromosomes
5. Sister chromatids

**Meiosis I**

1. Homologous chromosomes separate
2. Haploid cells with replicated chromosomes

**Meiosis II**

1. Sister chromatids separate
2. Haploid cells with unreplicated chromosomes
The results of crossing over during meiosis

Prophase I of meiosis

Tetrad

Chiasma, site of crossing over

Metaphase I

Kinetochore microtubules

Metaphase II

Gametes

Recombinant chromosomes

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### Mitosis

**Prophase**
- Duplicated chromosome (two sister chromatids)
- Chromosome replication

**Metaphase**
- Chromosomes align at the metaphase plate

**Anaphase Telophase**
- Sister chromatids separate during anaphase
- Daughter cells of mitosis $2n$

### Meiosis

**Meiosis I**
- Parent cell (before chromosome replication)
- Chromosome replication
- Chiasma (site of crossing over)
- Tetrad formed by synapsis of homologous chromosomes

**Prophase I**
- $2n = 4$

**Metaphase I**
- Tetrads align at the metaphase plate

**Anaphase I Telophase I**
- Homologous chromosomes separate during anaphase I; sister chromatids remain together
- Daughter cells of meiosis I
- Haploid $n = 2$

**Meiosis II**
- Daughter cells of meiosis II
- No further chromosomal replication; sister chromatids separate during anaphase II

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Sources of genetic variation in sexually reproducing organisms

1. Independent assortment of chromosomes during meiosis
2. Crossing over during meiosis
3. Random fertilization
Independent assortment of homologous chromosome pairs at the metaphase plate in meiosis I

Possibility 1

Possibility 2

Two equally probable arrangements of chromosomes at metaphase I

Metaphase II

Gametes

Combination 1
Combination 2

Combination 3
Combination 4

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Cell Cycle

From mother cell to two daughter cells

Mitosis or Meiosis division of the nucleus
Cytokinesis division of the cytoplasm

www.cellsalive.com
Cell Division and Death

Normal growth and development require a balance between the rates of two processes

**Cell division** (Mitosis) of somatic cells

**Apoptosis** – Programmed Cell death

Necrosis versus apoptosis

http://bio-animations.blogspot.com/2008/04/cell-death-necrosis-vs-apoptosis.html (not active anymore)
http://www.youtube.com/watch?v=4wPlw_Bdz7Q
Figure 2.13

Cell division

Cell death

Mitosis

Apoptosis

a.

b.
Apoptosis

Begins when a cell receives a “death signal”

Killer enzymes called **caspases** are activated
- Destroy cellular components

Dying cell forms bulges called blebs

Phagocytes digest the remains

http://www.youtube.com/watch?v=9KTDz-ZisZ0
http://www.youtube.com/watch?v=88YJSyPIOtU
Cell Cycle Control

• Frequency of cell division varies with the type of cell

• Cell cycle differences result from molecular control regulation system
Cell-Specific Frequency of Division of Normal Cells

- Very often
  - Skin cells
  - Bone marrow
  - Lining of stomach and intestines
- Sometimes
  - Liver cells
- Do not divide in mature animal
  - Nerve cells
Cell Cycle Control

Checkpoints ensure that mitotic events occur in the correct sequence

Internal and external factors are involved

Many types of cancer result from faulty checkpoints
Progression through cell cycle is controlled by regulatory proteins.

- DNA damage checkpoint: Inhibits cell cycle until DNA can be repaired.
- Spindle assembly checkpoint: Is spindle built? Do chromosomes attach to spindle? Are chromosomes aligned down the equator?
- Apoptosis checkpoint: If survivin accumulates, mitosis ensues.
- Overriding cell death:

Cell Cycle Control

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The Cell Cycle Control System of normal cells

Three major checkpoints are found in the G1, G2, and M phases

www.cellsalive.com
G1 Checkpoint

The restriction point in mammalian cells exits the cycle and switches the **G0 phase**.  
- Non-dividing adult cells  
- Liver cells can be “called back”  
- highly specialized, terminally differentiated, nerve and muscle cells
G2 Checkpoint

Ensures that errors of DNA replication have been repaired before mitosis is allowed to proceed (DNA repair), and prepares the cell for the events of the mitotic phase.
Metaphase (M) Checkpoint

- Anaphase is delayed until all the chromosomes are properly attached to the spindle at the metaphase plate.

- A signal to delay anaphase originates at kinetochores that have not yet attached to spindle microtubules.
Example of internal signals controlling cell cycle progression

**Kinetochore messages**

- Activation of the anaphase-promoting complex (APC) (remains inactive until it receives a signal from the kinetochore).

http://faculty.plattsburgh.edu/donald.slish/Anaphase%20transition.html
Programmed cell death is part of normal development

Cancer can result from too much mitosis, too little apoptosis, and loss of cell cycle control
Example of **external control signals**

**Growth factors**: Platelet derived growth factor (PDGF) stimulates fibroblast division

http://highered.mcgraw-hill.com/sites/0072437316/student_view0/chapter11/animations.html#
Behavior of normal and cancer cells in cell culture

Density-dependent inhibition of cell division

Mortality of cells-limited numbers of cell divisions

Anchorage dependence of cells
Cancer cells
- Do not respond normally to control mechanisms
- Form tumors

1. A tumor grows from a single cancer cell.
2. Cancer cells invade neighboring tissue.
3. Cancer cells spread through lymph and blood vessels to other parts of the body.

The growth and metastasis of a malignant breast tumor that escaped cell cycle control.