Biology is the only subject in which multiplication is the same thing as division…

The Cell Cycle: Cell Growth, Cell Division

Getting from there to here…
- Going from egg to baby….
  - the original fertilized egg has to divide…
    - and divide…
    - and divide…
    - and divide…

Why do cells divide?
- For reproduction
  - asexual reproduction
    - one-celled organisms
- For growth
  - from fertilized egg to multi-celled organism
- For repair & renewal
  - replace cells that die from normal wear & tear or from injury

Making new cells
- Nucleus
  - chromosomes
  - DNA
- Cytoskeleton
  - centrioles
    - in animals
  - microtubule spindle fibers

Nucleus
- Function
  - protects DNA
- Structure
  - nuclear envelope
    - double membrane
    - membrane fused in spots to create pores
      - allows large macromolecules to pass through... What kind of molecules need to pass through?
The Cytoskeleton

- **Function**
  - **structural support**
    - maintains shape of cell
    - provides anchorage for organelles
      - protein fibers
        - microfilaments, intermediate filaments, microtubules
  - **motility**
    - cell locomotion
      - cilia, flagella, etc.
  - **regulation**
    - organizes structures & activities of cell

- **Centrioles**
  - **Cell division**
    - in animal cells, pair of centrioles organize microtubules
      - spindle fibers
      - guide chromosomes in mitosis

- **Getting the right stuff**
  - What is passed on to daughter cells?
    - exact copy of genetic material = DNA
      - mitosis
    - organelles, cytoplasm, cell membrane, enzymes
      - cytokinesis

- **End of the Tour**
  - chromosomes (stained orange) in kangaroo rat epithelial cell
  - notice cytoskeleton fibers
Overview of mitosis

- **Interphase**
  - 90% of cell life cycle
  - Cell doing its “everyday job”
    - Produce RNA, synthesize proteins/enzymes
    - Prepares for duplication if triggered

**Interphase**
- Divided into 3 phases:
  - \( G_1 \) = 1st Gap (Growth)
  - Cell doing its “everyday job”
  - Cell grows
  - DNA synthesis
  - Copies chromosomes
  - \( G_2 \) = 2nd Gap (Growth)
  - Prepares for division
  - Cell grows (more)
  - Produces organelles, proteins, membranes

**Cell cycle**
- Cell has a “life cycle”
  - Cell is formed from a mitotic division
  - Cell grows & matures to divide again
  - Cell grows & matures to never divide again
  - \( G_1, S, G_2, M \)
  - Liver cells
  - Epithelial cells, blood cells, stem cells
  - Brain / nerve cells
  - Muscle cells

**Interphase**
- Nucleus well-defined
  - DNA loosely packed in long chromatin fibers
- Prepares for mitosis
  - Replicates chromosome
    - DNA & proteins
  - Produces proteins & organelles

**S phase: Copying / Replicating DNA**
- Synthesis phase of Interphase
  - Dividing cell replicates DNA
  - Must separate DNA copies correctly to 2 daughter cells
    - Human cell duplicates ~1-2 meters DNA
    - Each daughter cell gets complete identical copy
    - Error rate = ~1 per 100 million bases
      - 3 billion base pairs in mammalian genome
      - ~30 errors per cell cycle
        - Mutations (to somatic (body) cells)
**Organizing DNA**

- DNA is organized in **chromosomes**
  - double helix DNA molecule
  - wrapped around **histone proteins**
    - like thread on spools
  - DNA-protein complex = **chromatin**
    - organized into long thin fiber
  - condensed further during mitosis

**Copying DNA & packaging it...**

- After DNA duplication, chromatin **condenses**
  - coiling & folding to make a smaller package

**Mitotic Chromosome**

- Duplicated chromosome
  - 2 **sister chromatids**
  - narrow at **centromeres**
  - contain identical copies of original DNA

**Mitosis**

- Dividing cell’s DNA between 2 daughter nuclei
  - “dance of the chromosomes”
- 4 phases
  - **prophase**
  - **metaphase**
  - **anaphase**
  - **telophase**

**Prophase**

- Chromatin condenses
  - **visible chromosomes**
  - **chromatids**
- **Centrioles** move to opposite poles of cell
  - animal cell
- Protein fibers cross cell to form **mitotic spindle**
  - microtubules
    - actin, myosin
  - coordinates movement of chromosomes
- **Nucleolus disappears**
- **Nuclear membrane breaks down**
Transition to Metaphase

- **Prometaphase**
  - Spindle fibers attach to centromeres
  - Creating kinetochores
  - Microtubules attach at kinetochores
  - Connect centromeres to centrioles
  - Chromosomes begin moving

Metaphase

- **Chromosomes align along middle of cell**
  - **Prometaphase**
    - Meta = middle
  - Spindle fibers coordinate movement
  - Helps to ensure chromosomes separate properly
    - So each new nucleus receives only 1 copy of each chromosome

Anaphase

- **Sister chromatids separate at kinetochores**
  - Move to opposite poles
  - Pulled at centromeres
  - Pulled by motor proteins “walking” along microtubules
    - Actin, myosin
    - Increased production of ATP by mitochondria
  - Poles move farther apart
    - Polar microtubules lengthen

Separation of chromatids

- In anaphase, proteins holding together sister chromatids are inactivated
  - Separate to become individual chromosomes

Chromosome movement

- Kinetochores use motor proteins that “walk” chromosome along attached microtubule
  - Microtubule shortens by dismantling at kinetochore (chromosome) end
**Telophase**
- Chromosomes arrive at opposite poles
  - daughter nuclei form
  - nucleoli form
  - chromosomes disperse
    - no longer visible under light microscope
- Spindle fibers disperse
- Cytokinesis begins
  - cell division

**Cytokinesis**
- Animals
  - constriction belt of actin microfilaments around equator of cell
    - cleavage furrow forms
    - splits cell in two
    - like tightening a draw string

**Cytokinesis in Animals**
- Animals
  - constriction belt of actin microfilaments around equator of cell
    - cleavage furrow forms
    - splits cell in two
    - like tightening a draw string

**Mitosis in whitefish blastula**
- Inteplase
- Prophase
- Metaphase

**Mitosis in animal cells**
- Interphase
- Prophase
- Metaphase

**Cytokinesis in Plants**
- Plants
  - cell plate forms
    - vesicles line up at equator
    - derived from Golgi
    - vesicles fuse to form 2 cell membranes
  - new cell wall laid down between membranes
  - new cell wall fuses with existing cell wall

**Cytokinesis in Plants**
- Cells
  - daughter nuclei form
  - nucleoli form
  - chromosomes disperse
    - no longer visible under light microscope
- Spindle fibers disperse
- Cytokinesis
  - cell division

**Cytokinesis in Plants**
- Plants
  - constriction belt of actin microfilaments around equator of cell
    - cleavage furrow forms
    - splits cell in two
    - like tightening a draw string
Mitosis in plant cell

Cytokinesis in plant cell

Evolution of mitosis

- Mitosis in eukaryotes likely evolved from binary fission in bacteria
  - Single circular chromosome
  - No membrane-bound organelles

A possible progression of mechanisms intermediate between binary fission & mitosis seen in modern organisms

Any Questions??
Control of Cell Cycle

- **Interphase**: The cell will continue to grow and produce new proteins required for cell division.
- **G1**: Cells increase in size, produce RNA and protein synthesis.
- **S**: DNA is replicated.
- **G2**: Cells increase in size, produce RNA and protein synthesis.
- **M (Mitosis)**: Cells divide into two daughter cells.

Kinetochore

- Each chromatid has its own kinetochore proteins.
- Microtubules attach to kinetochore proteins.

Chromosome structure

- Scaffold protein
- Chromatin loop
- 30 nm thick DNA filament
- Nucleosome
- Histone
- Rosettes of chromatin loops
- Chromosome

DNA double helix

Nucleosome